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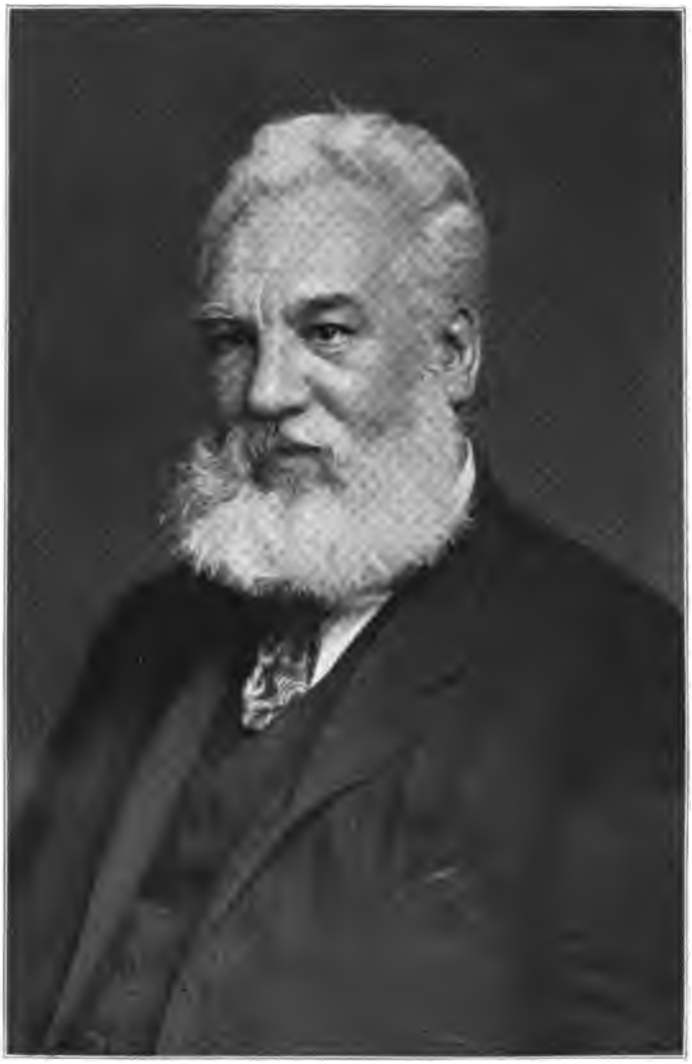

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Inventor of the Electric Telephone,
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CYCLOPEDIA

of

Applied Electricity

A Practical Guide for

**ELECTRICIANS, MECHANICS, ENGINEERS, STUDENTS,
TELEGRAPH AND TELEPHONE OPERATORS,
AND ALL OTHERS INTERESTED
IN ELECTRICITY**

Prepared by a Corps of

EXPERTS, ELECTRICAL ENGINEERS AND DESIGNERS

Illustrated with over Two Thousand Engravings

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The standard technical literature of Europe and America has been freely consulted in the preparation of these volumes. The editors desire to express their indebtedness, particularly to the following eminent authorities, whose well-known treatises should be in the library of every Electrician and Engineer.

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Preface

REALIZING the great need for a more scientific knowledge of electricity on the part of thousands of practical men of limited technical education, an attempt has been made in the following pages to give a presentation of the subject which shall be easily understood by such men, and at the same time, cover all the essential principles and methods. The principles usually deduced by higher mathematics are here made clear by careful explanation and a large number of diagrams drawn especially for the text. Numerous engravings exemplify modern practice, and form a pictorial index to the latest and best methods of applying electricity to lighting, railways, power transmission, machine tools, etc.

¶ The Cyclopedia of Applied Electricity is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching practical electricians the scientific principles underlying their work. It is compiled from the most valuable of the School's Instruction Papers and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained in teaching thousands of electricians is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature, representing as they do the best methods of a large number of *different* authors, each an acknowledged authority in his work,—they are by no means an experiment, but are in fact the essence of the most successful method yet devised for the education of the busy working man.

¶ Among the sections of most practical value are those on Alternating Current Machinery, Storage Batteries, Electric Wiring, Lighting, etc. In these pages the authors have succeeded in presenting the subjects in such manner as to overcome the hitherto insurmountable obstacle—higher mathematics. The rules and formulae are presented in a very simple manner, and special effort has been made to illustrate every principle by diagrams and practical examples.

¶ Numerous examples for practice are inserted at intervals; these with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience, and teachers of acknowledged ability—has alone made these volumes possible.

¶ The Cyclopedia is published in the belief that it will meet a real need among designers, constructors and operators of electrical machinery. That it may save many weary hours of search among the scattered textbooks and reference works of the day,—books which being intended largely for college-trained men are necessarily far from meeting the needs of the average practical man,—is the hope of the compilers and publishers.

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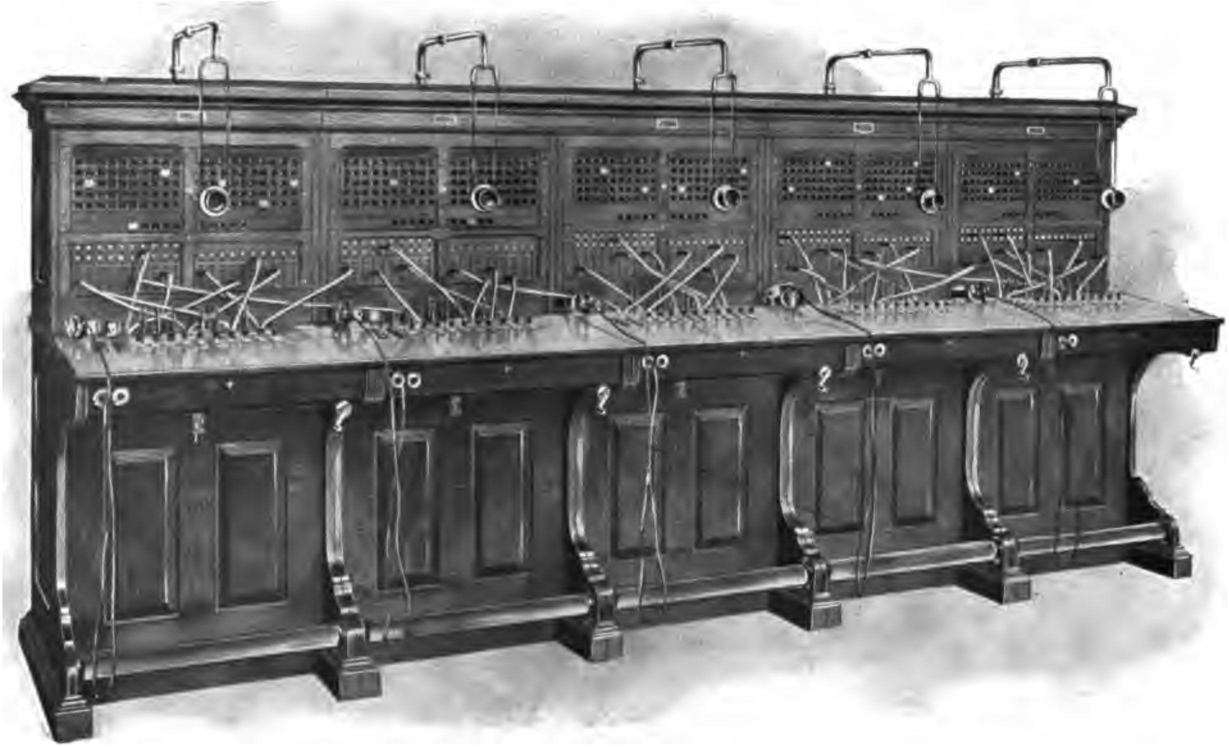

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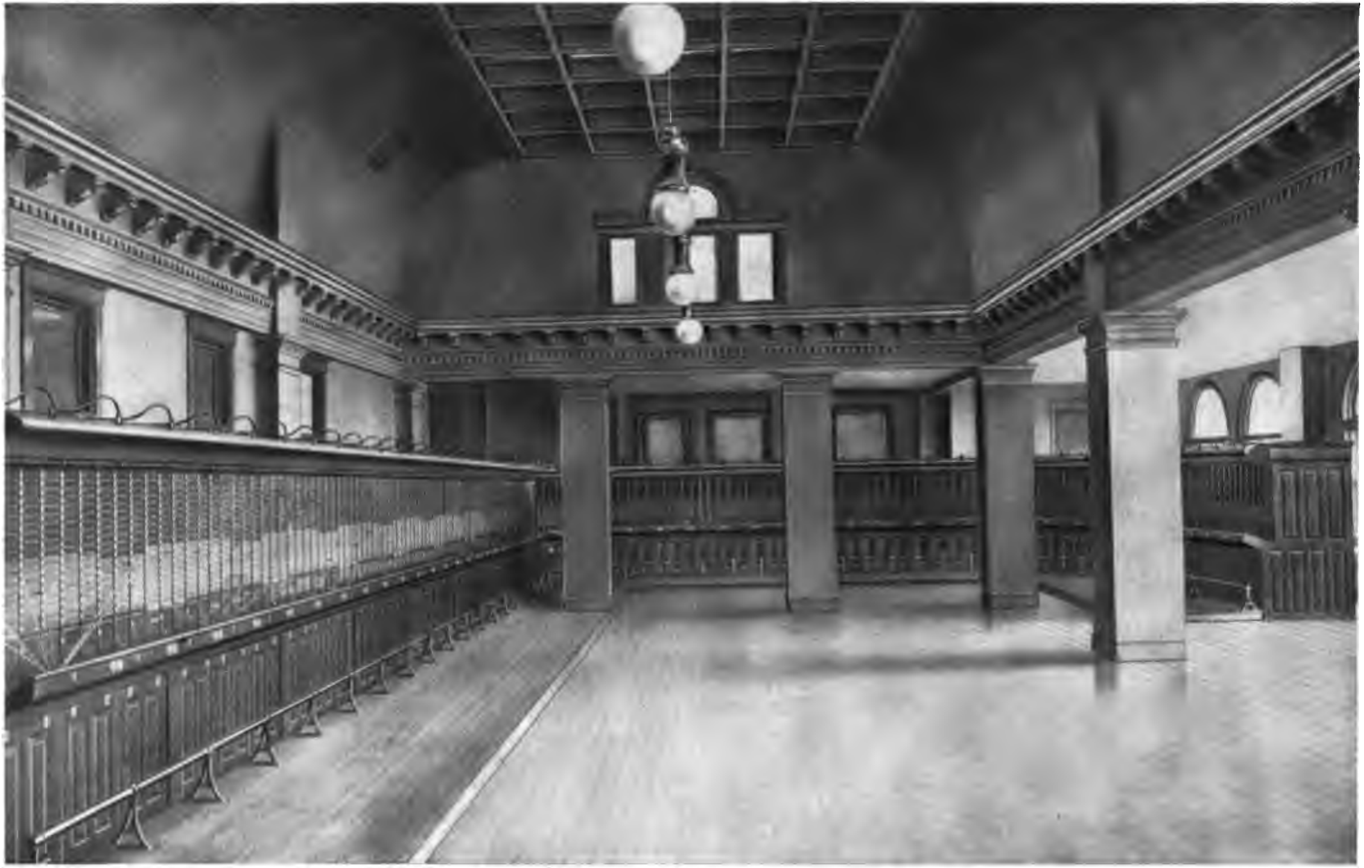

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TELEPHONY

PART I.

To properly understand the manner in which sound is transmitted from one end of an electric circuit to the other, it will be necessary to entirely get rid of a popular idea, and to fix clearly in mind, at the outset, the process that actually takes place. The popular idea referred to is, that the sound produced at one end of a circuit actually travels over that circuit, in order to be heard at the other end. That is erroneous; in reality the actual sound produced at one end of the circuit, properly equipped with telephone apparatus, travels no farther than it would if the telephone apparatus were not present. What actually takes place is a process conforming to the law of Conservation of Energy. It may be described as follows: The sound energy produced in the presence of the telephone apparatus is transformed by that apparatus into electric energy, which, traveling to the distant end of the line, is again retransformed by the distant apparatus into sound energy. The sound energy thus reproduced, being an exact counterpart of the original, produces on the human ear the same effect, and therefore can not be distinguished from it.

Nature of Sound. Sound may best be defined as the effect produced on the ear drum by wave motions in the air particles. Every-day experience offers many proofs of this statement. If a man be observed while in the act of hammering nails into a plank, it will be found that, at a distance of about ten feet, the instant the hammer head strikes the nail a sensation is produced on the ear, which is recognized as the sound of the impact. A little reflection will convince the observer that, although separated from the point of impact by ten feet, the result of that impact is transmitted in some manner through the intervening space, and made to impress the ear with the sense of sound. In other words, the disturbance caused at the source of the sound is carried through the intervening space, and in turn affects the auditory nerves in such a manner as to produce sound. If no intervening objects exist, such as a board fence or house, it will be found that the sound may be heard with equal distinctness at any point of a sphere whose radius is ten feet and whose center lies at the point of impact. It therefore becomes established that the disturbance caused by the hammer striking the nail is transmitted with equal intensity along all lines radiating from the point of impact.

Let the observer walk away from the man in question, continuing, however, to keep him under observation. He will note that, as the distance increases perceptibly, the sound of the blow will no longer occur at the same instant that the hammer is seen to strike, but at an appreciable time afterwards, and this interval will increase with the distance.

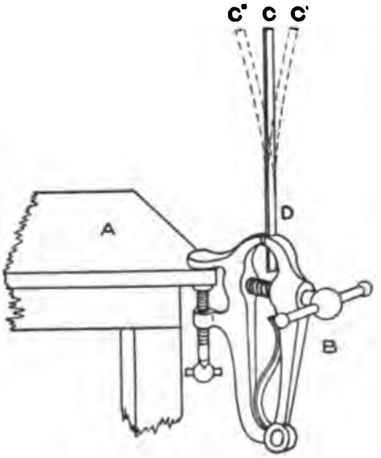


Fig. 1.

For a comparison between the phenomenon of sound which has just been observed, the workings of which cannot be seen with the eye, and some other phenomenon which can be seen, let us consider what happens when a stone is thrown into a pond whose surface is unruffled. Upon the stone entering the water a disturbance is produced, which radiates in waves in all directions. Any objects, such as chips of wood, that may be floating on the surface are agitated as the wave reaches them. Those nearest the point where the stone enters the water are set in motion sooner than those more remote. In fact, the wave can be observed to progress from the center of disturbance till it gradually dies out or strikes the shore.

From these simple observations, it is natural to imagine that sound consists of a wave motion among the particles of air, which motion progresses from the center of disturbance along the radii of a sphere. Other simple experiments will be made to prove that sound does really consist of wave motion among air particles.

In Fig. 1 let A be a table upon which is fastened a vice B in the jaws of which a flat piece of steel D is tightly held. If the free end of C be drawn to one side, as shown at C′, and then allowed to go free, the elasticity of the metal will cause it to return to the vertical position, beyond which the kinetic energy due to its motion will carry it to the other side, as shown at C″. From this position the elasticity will again cause it to return to the vertical, beyond which the kinetic energy will again carry it to some position between C and C′. The elasticity will again cause it to return to the vertical. This constantly decreasing motion will continue until the piece of steel gradually comes to rest. It is evident that the particles of air, directly surrounding the bar, will be given a similar motion to that of the steel. If the spring is made to move rapidly enough, a sound will be heard.

Referring again to the piece of steel: the motion of its end from C to C′ and back, or from C′ to C″, is called a *complete vibration*. The time taken to make a complete vibration is called a *period of vibration*.

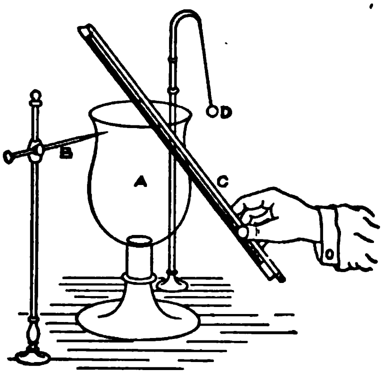


Fig. 2.

To prove that sounding bodies are in a state of vibration the following experiment is useful: In Fig. 2, let A be a glass bell-shaped jar, and B a fixed steel point which is separated from the surface of the jar by a very small space. If a resined violin bow C be drawn across the edge of the jar till it emits a musical note, a series of taps will be heard. They are caused by the glass bell, in its vibration striking against the point. If a pith ball D, be suspended so as to rest lightly against the side of the bell, it will be violently thrown away from the jar when a musical note is emitted.

If a glass plate A, Fig. 3, be secured at its center and supported on a table, it will, upon being agitated by a resined bow, emit a musical note. Suppose sand be strewed on its surface. If the plate is agitated, the sand will leave certain portions of the plate bare, and collect in definite lines on different portions of the plate. The lines so occupied by the sand are the places where the different waves of vibration meet to form *lines of rest.*

The above experiments are sufficient to prove that all sounding bodies are in a state of vibration, and that the phenomenon of sound is caused by this vibration being carried in wave motion by the air particles to the drum of the ear, and thence by the auditory nerves to the center of sound in the brain.

The student must not suppose that the sense of sound is caused by the particles of air, in actual contact with the sounding body, being projected against the ear drum. Such is not the case, any more than that the remote chips in the pond are set in motion by the particles of water at the point where the stone enters. What actually happens in the case of the pond is that the particles of water being thrown aside by the stone, set up by means of the elasticity of the water a vibratory motion in the adjacent particles. These in turn set up the same motion in those adjoining. Successive particles are thus set in motion by their neighbors, until the energy dies out, or until particles are reached which, being adjacent to the shore, have no fellows to which to transmit the vibration. The particles of water originally set in motion by the stone, continue to oscillate with a decreasing amplitude, at or very near their original locality, until they come to rest.

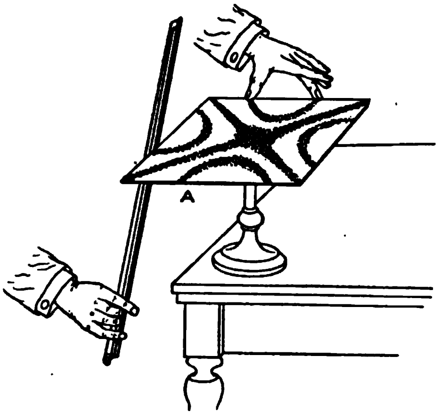


Fig. 3.

Similarly in the case of sound, the particles of air adjacent to the disturbing body are set in motion, and this motion is, through the elasticity of the air particles, transmitted to those next adjacent. These in turn transmit it to their neighbors until the motion dies out. When the particles of air adjacent to the ear drums are set in motion, the sensation of sound is produced. The particles disturbed remain in their original localities.

Air is not the only medium that will transmit sound. Metal, wood, water, and even earth, are useful in this respect. But for the present it will be sufficient to limit the discussion to sound transmission through air.

Let us consider again the experiment of throwing a stone into a pond. If the stone be of good size, such as is used in street paving, the waves caused thereby will, upon close observation, be found to be of different sizes. The largest wave will carry upon its surface waves of less and less magnitude, down to the size of ripples.

Nature of Sound Waves. The waves produced in water are the result of the particles of water being disturbed in a vertical direction, and the direction of wave propagation is therefore at right angles to the direction of the displacement of the particles. In the case of sound, the displacement of the air particles is in the same direction as that of the wave propagation. The displacement of the air particles consists of an oscillation to and fro in the direction of the wave propagation. These oscillations produce alternate pulses of condensation and rarefaction. which constitute the sound wave.

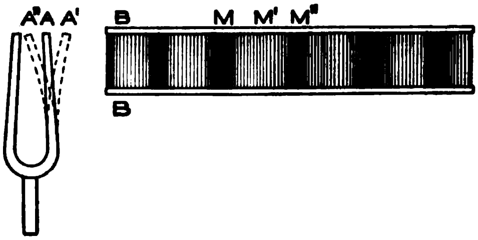


Fig. 4.

To illustrate more fully, suppose that in Fig. 4, A represents one of the prongs of a tuning fork which is vibrating in front of the open end of a tube BB filled with air. As the prong A moves toward the position A′ it pushes before it the adjacent particles of air, which in turn push their neighbors. The result is a pulse of compression in front of the fork. When the prong A has reached the position A′, it momentarily comes to rest, and consequently ceases to act on the air particles. The particles of air beyond are in a normal condition, because the pulse of compression has not yet had time to travel any appreciable distance. As the prong of the fork moves back from A′ to A″, a partial vacuum is formed, and the air particles begin to move in the direction of the fork, causing a pulse of rarefaction. By the time the prong has reached the position A″ and again comes to rest, the pulse of compression has moved to some point as M. The shaded lies denote the greater density of the air particles. With the pulse of rarefaction being formed at the fork, the air particles tend to rush that way, and by the time the fork has again reached the position A′, and a second pulse of compression formed, a pulse of rarefaction is found at M′ and the pulse of compression has moved to M″. This oscillation of the air particles continues in unison or harmony with that of the prong of the fork, causing successive pulses of compression and rarefaction to be sent through the air in the tube. The distance between the center of a wave of compression and a wave of rarefaction is called *one-half a wave length*, while the distance between two consecutive waves of compression is called a *whole wave length.* A wave length may be defined as the distance through which the pulse has traveled while the prong of the tuning fork has made one complete vibration, during which time each particle of air has gone through one complete cycle of changes, both as regards motion and density. The period of vibration to each particle is thus identical with the period of vibration of the prong of the tuning fork. It has been proven by experiment that the rate of sound traveling in air is 1,090 feet per second. Now, if the tuning fork vibrates at the rate of 435 complete vibrations per second, the period will be $\frac{1}{435}$ second, and the wave length will be $\frac{1090}{435} = 2$ feet and 6 inches, which is the wave length in air for this note.

Noise and Musical Sound. Thus far the discussion has been concerned only with sound waves of uniform length. It will be necessary at this point to inquire more specifically into the nature and construction of this wave. The discussion should be prefaced by this definition: The difference between noise and musical sound lies in the frequency of the disturbance. When the frequency exceeds 64 impulses per second, the human ear is not capable of distinguishing the separate impulses, but recognizes them only as a continuous sound. This fact may be illustrated by a piece of mechanism shown in Fig. 5, which consists of a toothed wheel, which can be made to revolve, while a piece of cardboard is firmly held in such a position that the teeth strike against it as they pass. If the number of teeth on the wheel is known, the number of revolutions of the wheel per second multiplied by the number of teeth will give the number of impulses given to the card in the same time. Rotating the wheel slowly at first, the separate impacts of the teeth against the cardboard are plainly discernable. As the wheel rotates faster, the separate impacts become less distinct, until when the number reaches 64 per second they merge into one another and become a musical note. If the speed of rotation be steadily increased from this point, the musical sound becomes steadily shriller, until it becomes so shrill, or, in other words, the frequency so high, that the ear is unable to take any cognizance of it.

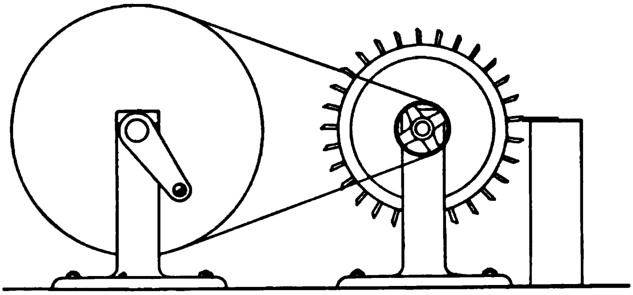


Fig. 5.

Musical sounds can be distinguished in three ways:

Loudness. This is the quality which, regarded subjectively, measures the intensity with which a musical sound affects the auditory nerve. This quality depends, for sounds of the same pitch and quality, on the energy of the vibration of the air particles adjacent to the ear drum, and is proportional to the square of the amplitude.

Pitch. This is the quality which distinguishes an acute sound from a grave one; for example, a treble note from a bass note. Pitch depends upon the frequency of vibration, rising as the frequency rises. This point is illustrated by means of the toothed wheel and the card.

Character. This is the quality which distinguishes between the sound of the human voice and that of a cornet; or between that of a violin and that of a French horn. The terms poor, harsh, rich, mellow, are used in this connection. The French call this quality *timbre;* while the Germans use the term *sound tint*, or *sound flavor.*

The point upon which the character of a sound depends was made a special study by the celebrated German scientist, Alexander Von Helmholz, and it may be explained as follows: The first essential characteristic of a musical note is that each vibration shall be exactly like its successor. In other words, the disturbance must be periodic. It has been shown by the French mathematician, Fourier, that any periodic vibration executed in one line can be definitely resolved into simple vibrations of which one has the same frequency as the given vibration, and the others have frequencies 2, 3, 4, 5, etc., times as great. The theorem may be briefly expressed by saying that every periodic vibration consists of a fundamental simple vibration and its harmonics. As a result of this reasoning, a sound wave caused by a musical note must always be considered as consisting of one simple vibration, corresponding in frequency to the pitch of the note, and several other vibrations whose frequencies are multiples of the first or fundamental. This point is exceedingly important and should be clearly understood. Speaking in the language of the musician, the fundamental vibration corresponding to the pitch of any note is called the *fundamental*, while the accompanying vibrations of higher frequency are called the *over-tones.* Helmholz determined that the character of a note depended on the number of *over-tones.* The vowel sounds used in speech are musical tones just as much as those used in singing, only they are not sustained as long. The laws governing their pitch intensity and character are therefore the same as those already described. To sum up, then, when a person is speaking, the surrounding air particles are agitated within the range of the voice by a periodic vibration whose frequency, and therefore wave length, corresponds to the pitch. Superimposed upon this vibration are others whose frequencies are multiples of the first and their wave lengths the corresponding fractions of the first.

The Nature of Electricity. Up to this point the subject of sound only has been considered. The object has been to fix clearly in mind the fundamental principles of the wave theory. The application will be seen when the action of the sound waves on the telephone instrument is considered. However, it will now be necessary to inquire into the subject of the generation of electric current. The flow of current in any circuit is given by Ohm's law, which is expressed: $I = \frac{E}{R}$ in which I represents the current in amperes, E the E. M. F. in volts acting in the circuit and R the resistance of the circuit expressed in ohms. From this equation it will be seen that to have a flow of current in an electric circuit, an E. M. F. or difference in potential is necessary. Therefore, the first point to be considered is the method of generating this E. M. F. E. M. F. may be generated in three ways: first, by chemical action between two or more bodies; second, by the heating of the junction point of two dissimilar metals; third, by the movement of a closed circuit in a magnetic field. For commercial purposes the first and third methods only are common. The second method is used only in laboratory experiments. The apparatus by means of which chemical action generates electric current is called a battery. A mechanism which is used to generate E. M. F. by moving a closed circuit in a magnetic field is called a dynamo or generator.

Batteries are divided into two classes, Primary and Secondary. A primary battery may be defined as one in which chemical action takes place directly to produce the E. M. F., while in a secondary battery the E. M. F. is produced by the chemical action set up after a current of electricity has been passed through the cell for some time. Secondary batteries are commonly called storage batteries.

There are many types of primary batteries, each possessing peculiar features. In telephone practice, however, the types available are limited to a few that meet the peculiar conditions required. They are, first, the Gravity Battery; second, the Leclanche Battery; third, the Fuller Battery; fourth, the Edison-Laland Battery; fifth, some forms of dry battery.

Gravity Battery. In all forms of primary battery the E. M. F. is generated by chemical action taking place between two dissimilar bodies called the *elements*, which are surrounded by a liquid called the *electrolyte*. The whole is encased in a glass jar. The electrical potential generated in the cell depends on the nature of the substances used as elements. In the gravity cell the elements consist of metallic zinc and metallic copper, and the electrolyte is a solution of copper sulphate in water. The generation of E. M. F. is attended by certain chemical changes which take place in the cell. The oxygen from the water attacks the zinc element forming an oxide of zinc, which in turn combines with the sulphuric acid to form zinc sulphate, setting free the hydrogen. The hydrogen thus released attacks the copper sulphate, displacing the copper and forming sulphuric acid, and depositing the copper in metallic form. The newly formed sulphuric acid again attacks the oxide of zinc, forming additional zinc sulphate and again releasing hydrogen, which in turn displaces metallic copper as before. As a result of this chemical action the elements remain in the form of metallic zinc and metallic copper.

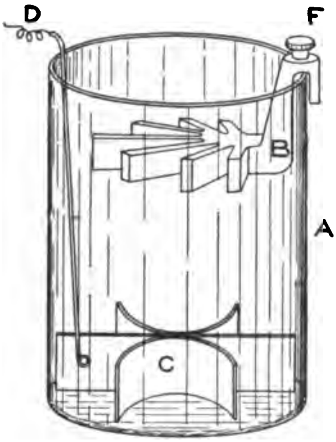


Fig. 6.

Polarization. By the term polarization of a cell is meant the collecting of bubbles of hydrogen on the copper or negative element. These hydrogen bubbles have an E. M. F. opposite to that set up by the zinc element, and as a result the two E. M. F.'s of the cell, that due to the potential difference between the zinc and the copper, and that due to the potential difference between the hydrogen bubbles and the zinc, are opposed to each other. When this condition exists, the cell is said to be polarized and the current ceases to flow. Since the hydrogen gas does not collect on the copper plate, but is combined with the sulphate, polarization does not take place in the gravity cell.

Fig. 6 shows a cell of a gravity battery. Here the glass jar is shown at A, the zinc element at B, and the copper element at C. To the copper element is soldered an insulated wire D, while the zinc element is shaped to fit firmly over the top of the jar and carries on its upper surface a binding post F. The copper sulphate (blue crystals) is placed in the jar and sufficient water poured in to bring the level just above the upper surface of the zinc. In setting up batteries of this type from 3 to 3½ pounds of copper sulphate crystals are placed in the bottom of the jar surrounding the copper element. The crystals should be small enough to pass through a sieve with a 1¼-inch mesh, and should not be so small as to pass through a $\frac{3}{16}$-inch mesh. The water is then poured in until the zinc element is submerged. The battery is then short-circuited for about 24 hours. This short circuiting puts the cell into action, with the result that zinc sulphate is formed. This zinc sulphate solution gathers about the zinc element and therefore forms the upper third of the electrolyte. The lower two-thirds of the electrolyte is composed of copper sulphate solution which is indicated by a deep blue color. When a cell of this type is in good condition a distinct line separates the copper sulphate solution from the colorless zinc sulphate solution above. As the liquid of the cell evaporates, the zinc sulphate is deposited over the edge of the jar. In a short while this deposit, which is in the form of white crystals, becomes very thick and reduces the efficiency of the cell. To prevent this a layer of oil about ⅛ inch deep is placed on the top of the electrolyte. This oil, by preventing evaporation, makes it impossible for the zinc sulphate crystals to be deposited. The E. M. F. of the gravity cell is 1.079 volts, and the internal resistance varies between 2 and 3 ohms, depending on the size of the plates, their nearness together, and the nature of the electrolyte.

The Leclanche Cell. In this form of battery the elements consist of zinc and carbon, the latter being encased in a porous cup; the electrolyte is a solution of chloride of ammonium, commonly known as sal-ammoniac. The action in this cell during the passage of the current is as follows: The chloride of ammonium is decomposed, the chlorine leaving the ammonia and hydrogen to unite with the zinc elements, forming chloride of zinc. The ammonia is dissolved in the water. The hydrogen enters the porous cup and would soon polarize the cell by collecting on the carbon plate were not some provision taken to prevent this action. Closely packed around the carbon element within the porous cup are crystals of peroxide of manganese, which yield up a part of their oxygen, forming water by combination with the hydrogen. The peroxide is thus reduced to a sesque-oxide of manganese. When the battery is delivering its normal current, the hydrogen is set free in a slightly larger quantity than can be absorbed by the manganese. Polarization, therefore, takes place, although very slowly; it becomes noticeable where the cell has been in use for a very long time, and then quickly disappears upon the cell being cut out of service. The E. M. F. of this type of cell is 1.47 volts, and its internal resistance is about 1 ohm.

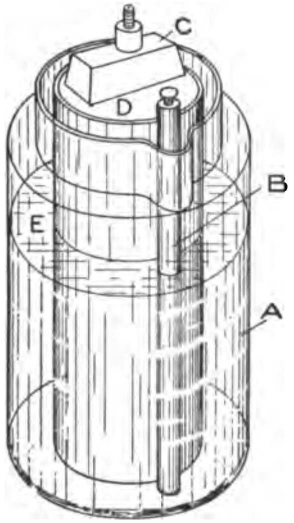


Fig. 7.

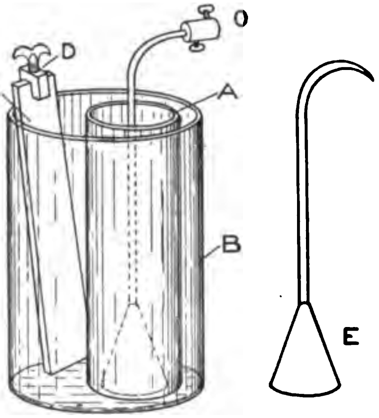


Fig. 8.

In Fig. 7 is shown a Leclanche cell, the jar being shown at A, the zinc at B, the carbon at C and the porous cup at D. The solution of water and sal-ammoniac is shown through the jar at E.

The Fuller Cell. This type employes for its elements zinc and carbon. The electrolyte consists of a solution of 3 parts bichromate of potash, 1 part sulphuric acid and 9 parts water. The zinc is placed in a porous cup in the bottom of which is placed about 2 ounces of mercury. There is also placed in the porous cup a solution of chloride of sodium in water, of sufficient depth to completely cover the zinc. The mercury in the porous cup is to keep the zinc thoroughly amalgamated, or coated with a layer of mercury. If this were not done the impurities which are always present, even in the best zinc, would, with dilute acid, set up chemical action in the zinc, thereby causing it to waste away, thus reducing the efficiency of the cell. The bichromate of potash is a combination of oxygen and the metals chromium and potassium. When the circuit of the cell is completed and the current flows, the sulphuric acid which passes through the porous cup attacks the zinc, forming zinc sulphate and setting free the hydrogen. This hydrogen combines with the oxygen of the bichromate of potash, thus preventing polarization.

The E. M. F. of the Fuller Cell is 2.028 volts, and its internal resistance about .5 ohm. The Fuller battery is shown in Fig. 8. The porous cup A is shown inside of the glass jar B; the carbon C is equipped at the top with a binding post D. The zinc is shown dotted inside of the porous cup and is also shown separately at E. O is a form of connector used with this type of cell on the zinc element; one end is fastened to the wire attached to the zinc and the other end holds the wire from the circuit. The two thumb screws insure good contact.

Edison-Lalande Cell. The elements of this cell are zinc and copper oxide, and the electrolyte is oxide of potassium or caustic potash dissolved in water. Polarization is prevented by the decomposition of the water of the solution, which results in the oxygen combining with the zinc to form zinc oxide. This zinc oxide combines with the potash to form a soluble double salt of zinc and potash. The hydrogen of the water combines with the oxygen of the copper oxide to form water and deposit metallic copper. The copper oxide used in this type of cell is formed by roasting copper scraps, ground finely and formed into blocks. As in the case of the gravity battery, a layer of oil is placed upon the top of the solution, to prevent evaporation and the formation of "creeping salts." It also prevents the formation of carbon dioxide with the potassium solution. In order to produce a minimum internal resistance, a film of metallic copper is placed on the copper oxide before the battery is put into use.

The E. M. F. of the cell is about .98 volt at starting, but falls to .75 volt after the cell has been running for a short time. The internal resistance, however, is very low, being about .025 ohm for the largest cells. This type, owing to its low internal resistance, is especially adapted to the production of strong currents.

Dry Battery. This type is made in several styles, all of which use zinc and carbon for their elements. While the term "dry" is applied to this cell, the application of the term is not strictly correct. However, the electrolyte is so prepared that it cannot be spilled out of the jar, thus making it especially adapted for portable use. The two typical forms of this cell are the Burnley and the Cassner. In both these types the glass jar is replaced by a zinc cup, which serves the double purpose of being the retaining cup and the positive element.

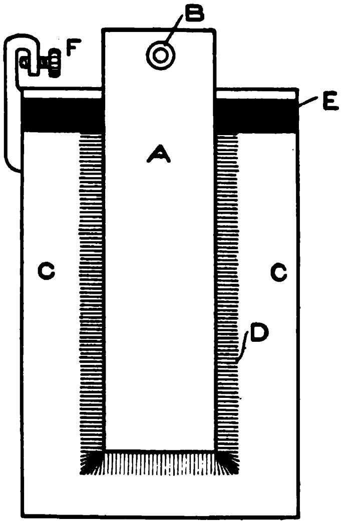


Fig. 9.

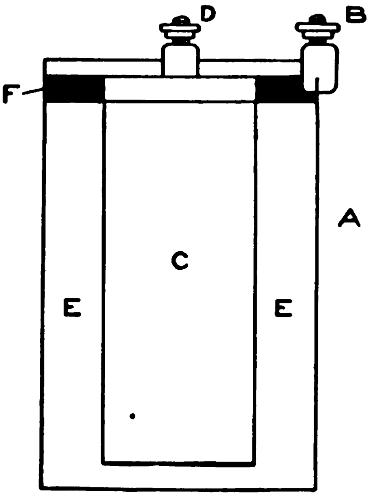


Fig. 10.

Burnley Cell. Here the carbon element is in the form of a solid cylinder A, Fig. 9, which is provided with the usual binding post B. Inside of the zinc cup is the electrolyte C, which is composed of 1 part sal-ammoniac, 1 part chloride of zinc, 3 parts plaster, 87 parts flour and 2 parts water. This compound, when mixed, is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent D is peroxide of manganese, the same as used in the Leclanche cell, and is packed around the carbon cylinder. The top of the cell is sealed with bitumen E or its equivalent. The binding post F is fastened to the zinc cup. It will be seen that the cell is proof against spilling. The E. M. F. of this cell is 1.4 volts, while the internal resistance is about 1 ohm.

Cassner Cell. This type is shown in Fig. 10, in which A represents the zinc cup with its attached binding post B, C the negative element which consists of carbon and manganese, and carries at its top the binding post D. The electrolyte, shown at E, consists of the following mixture: 1 part oxide of zinc, 1 part sal-ammoniac, 3 parts plaster, 1 part chloride of zinc and 2 parts water. No special depolarizing agent is needed, as the zinc oxide tends to loosen the compound and make it porous, thus facilitating the interchange of gases. The sealing compound is shown at F.

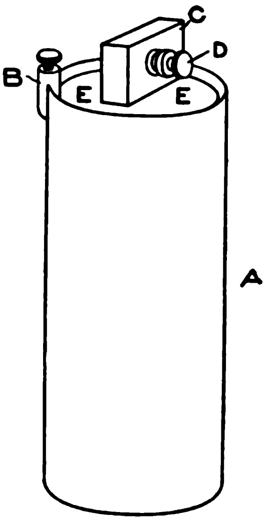


Fig. 11.

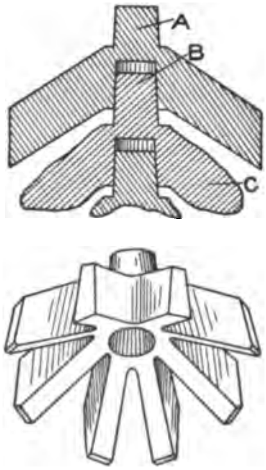


Fig. 12.

Fig. 11 shows the general appearance of a dry battery, A being the zinc cup with its binding post B, and C the end of the carbon element with its binding post D. The sealing compound is shown at E.

Wasteless Zinc. This is a type of zinc devised for use with the gravity battery; it is shown in Fig. 12. The zinc is equipped on the upper side with a conical-shaped projection A, and on the under side with a similarly shaped depression B. When a zinc has become so far eaten away as to be useless a new one is added, and the projection on the old one is fitted into the depression in the new one, so that it may remain in use until completely consumed. The old zinc thus fitted into the new one is shown at C.

The general appearance of the cell is shown in Fig. 13. The new zinc A is fastened to the supporting clamp B which rests upon the edges of the jar. The old zinc is shown at C. By the use of this type of zinc and the gaining of greater zinc surface the internal resistance of the cell is reduced to .7 ohm.

Secondary or Storage Batteries. Thus far the only types of batteries discussed are those which produce an E. M. F. from the chemical changes which go on within the cell. A different type of cell must now be considered. In this type a current of electricity is first used to produce certain chemical changes and store up certain chemical affinities. These chemical affinities are then allowed to act, and in so doing produce an E. M. F. This type of cell is called a Storage or Secondary cell.

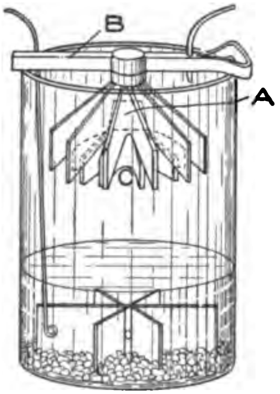


Fig. 13.

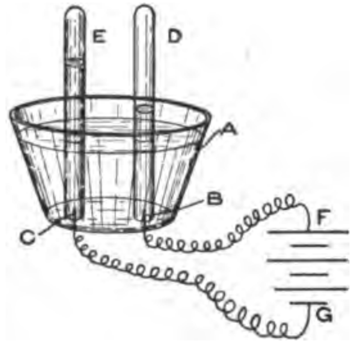


Fig. 14.

The most simple type of storage battery, and at the same time the type most suited to illustrate the principle upon which it works, is the one in which a current of electricity is made to pass through water. The action of the current is to decompose the water into its constituent elements hydrogen and oxygen. The hydrogen is collected on the negative pole and the oxygen on the positive. In Fig. 14 is shown a tank A containing water. The two terminals of an electric circuit are introduced into the tubes D and E at B and C. When the current passes, the water is decomposed; hydrogen is collected in the upright arm D of the tube, while oxygen is collected in the arm E. If, after the water has been decomposed, the source of current is removed and the two terminals or electrodes F and G connected, the gases in uniting to again form water will generate an electric current. While this form of storage battery is useful for illustrative purposes, it is useless commercially.

The storage battery commonly used today consists of two elements of lead immersed in a solution of sulphuric acid and water. In the early form, the elements consisted of thin sheets of metallic lead. When a current of electricity passed through the cell, the water in the sulphuric acid decomposed and the oxygen passed to the positive plate and united with the metallic lead to form on its surface a red peroxide of lead. The hydrogen was set free at the negative plate. The charging current being removed and the two elements connected electrically a current was generated by the oxygen in the lead peroxide reuniting with the hydrogen and forming water. The positive plate was thereby reduced again to metallic lead. The current continued to flow until the lead peroxide disappeared. The forming of lead peroxide on the positive plate renders its surface spongy and porous, and, presenting more surface, renders it capable of forming and retaining a greater amount of lead peroxide upon the second charge than upon the first. Consequently this type of cell had to be charged and discharged several times before the positive plate was sufficiently porous to bring the cell up to its maximum efficiency. This charging and discharging is called *forming*.

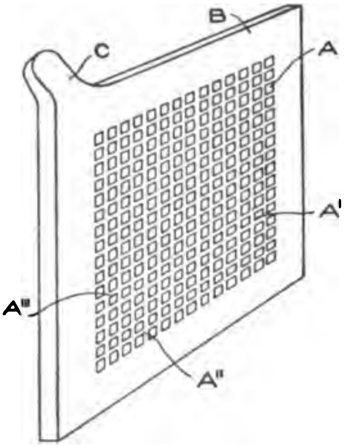


Fig. 15.

As the process of forming necessitated the waste of a great deal of current, the chloride plate was introduced. It has proved to be the best and is now used almost universally. It is constructed as follows: A specially prepared "tablet" is made by rolling into spiral form a strip of corrugated lead $\frac{1}{4}$ inch in width; the size of the spiral being $\frac{5}{8}$ inch in diameter. A sheet of metallic lead is moulded under pressure around several of these tablets, the whole presenting an appearance as shown in Fig. 15, where A, A′, etc., represent the tablets and B the lead plate. Each lead plate is provided with a lug C for connecting two or more plates and also to provide a terminal for the circuit.

The term "chloride" comes from the fact that the lead is derived from lead chloride, but no chlorine is used in the manufacture of the battery. In general the tablets for the positive plates are made circular, while those used in the negative plates are square. The plates intended for the positive element are immersed in sulphuric acid, through which a current is passed in one direction for about fifteen days. In so doing the lead of the tablets is converted into lead peroxide or active material. They are then ready to be set up in the cell with the negative plates.

There are two distinct chemical actions that take place in the storage battery; one during the charge and the other during discharge. The sulphuric acid acts upon the lead of the negative plate to form lead sulphate. When the charging current is passed, this lead sulphate is broken up into lead peroxide, PbO_2. This is deposited upon the positive plate. The metallic lead is formed on the negative plate. The sulphate is liberated into the electrolyte. Expressing this chemical action as a chemical equation:

$$2\,Pb\,S\,O_4 = Pb + Pb\,O_2 + 2\,S\,O_3$$

which means that the lead sulphate is broken up into $Pb\,O_2$, lead peroxide, Pb lead and SO_3 the sulphate. This sulphate combining with the water $(H_2\,O)$ forms sulphuric acid, $H_2\,OSO_3$, or, as it is generally written, $H_2\,SO_4$.

When the cell is discharged the reverse action takes place, and one atom of oxygen leaves the lead peroxide to unite with the hydrogen of sulphuric acid to form water. The sulphate in the electrolyte unites with the lead monoxide to form sulphate of lead on the negative plate; metallic lead is converted to sulphate on the positive.

$$Pb + Pb\,O_2 + 2\,H_2\,SO_4 = 2\,H_2\,O + 2\,Pb\,SO_4$$

It will be apparent from these considerations that during charging the specific gravity of the solution increases, and that while discharging the reverse takes place. The resistance of the electrolyte varies with its density within certain limits, decreasing as the density increases. The density of the electrolyte is very important and should be watched with great care. It is measured by an instrument called a hydrometer.

The hydrometer consists of a glass bulb (A Fig. 16) about 1 inch in diameter. To this bulb is attached a hollow glass stem B about 5 or 6 inches long. A quantity of small shot is placed in the bottom of the bulb, sufficient to sink it to the desired depth in pure water. On the stem is a graduated scale D resembling somewhat that of a thermometer. The height at which the instrument floats will depend on the density of the liquid in which it is placed. On a scale so marked that the point at which it floats in pure water is 1,000, the density of the storage battery solution would be 1,200. At the end of discharge the density falls to about 1,190.

The E. M. F. of a cell when fully charged is 2.4 volts. In discharging it should never be allowed to fall below 1.9 volts. The average voltage is about 2.1 volts. The internal resistance of this class of cell is very low, being about .02 ohm.

The capacity of a storage battery is rated in ampere-hours. This means the ability to deliver a certain number of amperes for a given number of hours. For example, if a cell delivered 10 amperes for 10 hours, its capacity would be 10 × 10 = 100 ampere-hours. This same cell would deliver 1 ampere for 100 hours.

Another property which a storage battery possesses is the *rate of charge and rate of discharge*. This is measured in amperes. The battery above referred to has a rate of discharge of 10 amperes.

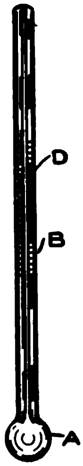


Fig 16..

On account of the losses in the battery, the charging rate should always exceed the rate of discharge by about 10 per cent. The rate of discharge should never be exceeded, as in so doing the battery will certainly be injured. The trouble caused by over-discharge is called buckling, and means a bending of the positive plates. This bending is destructive in two ways: first, it loosens the lead tablets; and second, it causes short circuits by the bent plate touching the one next adjacent. When a plate becomes bent it must be removed from the cell and straightened or a new one substituted.

In setting up a storage battery, the plates must be carefully dusted before they are placed in the jars, care being taken to separate and insulate the negative from the positive elements. In the smaller types, the plates are insulated by sheets of asbestos. In the larger sizes, the insulation is secured by placing glass rods between the plates, extending from the top to the bottom. The plates having been placed in the jar, the lugs are scraped clean, and all those on the positive plates are soldered together, as are those on the negative elements. The solution is then poured in and the charge begun at once. The utmost care should be taken not to leave the elements in the acid without immediate charging, otherwise sulphating will take place. The first charge should be carried on for a much longer time than that normally required; for example, about 18 or 20 hours at the normal rate for an 8-hour charge. The cell may then be discharged at the normal rate until the voltage falls to 1.9 volts. It should then receive the regular charge, after which it is ready for work.

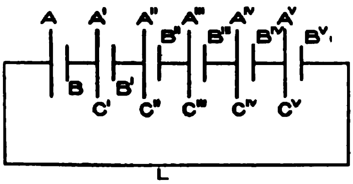


Fig. 17.

Arrangement of Cells Into Batteries. There are two ways of grouping cells into batteries: first, in *series;* second, in *multiple.* The first arrangement gives a total E. M. F. equal to the sum of the E. M. F's of each cell. The method of connecting cells in series is shown in Fig. 17, in which A, A′, A″, etc., represent a number of gravity cells. It will be seen that the zinc element B of the cell A is connected to the copper element C′ of the cell A′, while the zinc element B′ of the cell A″ is connected to the copper element C″ of the cell A″. This method is continued throughout; the zinc element of the last cell and the copper element of the first cell being connected to the line L. At this point it will be well

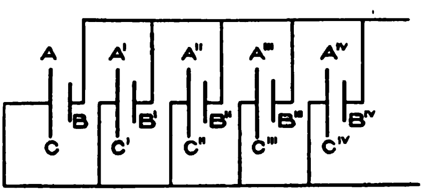


Fig. 18.

to remember that while the zinc element is electro-positive to the copper, and the current in the cell passes from one to the other with respect to the circuit; the copper element is the positive terminal and the zinc the negative. As a result, the current flows from the copper terminal of the first cell to the zinc terminal of the last, and so on through each cell back to the first.

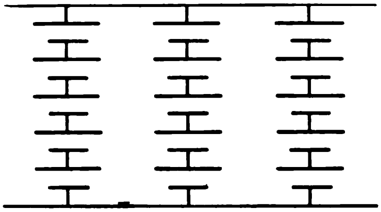


Fig. 19.

Fig. 18 shows the method of connecting cells in parallel or multiple. Here the copper elements C, C′, C″, etc., of the cells A, A′, A″, etc., are connected, as are the zinc elements B, B′, B″, etc. The copper terminal and the zinc terminal of cell A are connected to the line. With this arrangement the effective E. M. F. is that of one cell, but the current giving capacity is equal to that of one cell multiplied by the number of cells. The reason is that the internal resistance of the whole battery is equal to that of one cell *divided* by the number of cells.

We have already learned that the internal resistance decreases with the increase in the area of the elements. It is evident that under these conditions this area is equal to that of one element multiplied by the number of cells. A combination of these two arrangements can be obtained by connecting groups of cells in multiple, each group being made up of a number of cells connected in series, as shown in Fig. 19.

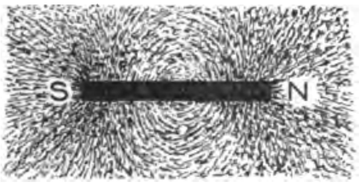


Fig. 20.

Magnetism. So far the production of E. M. F. by chemical action has been considered. Let us now investigate the third method of generating E. M. F. In this method a closed circuit is made to move in a magnetic field. The machine constructed to do this work is called a **dynamo or generator.** Before studying the generator it is well to know something of magnetism and the magnetic field. In Fig. 20 is shown a bar magnet, in which N and S represent the north and south poles, respectively. If this magnet is placed upon a table and covered with a thin sheet of paper, fine iron filings shaken over the paper will arrange themselves in curved lines radiating from each pole as shown. It will also be observed that the tendency of the filings is to form closed curves connecting the two poles. The space throughout which this effect of the magnet is manifest is called the *field;* the curves which the filings tend to form are called lines of *force.*

It is a well known fact that if a current is flowing through a conductor AB, Fig. 21, it will be surrounded by circular lines of force, as shown at C, C', C'', etc. These lines have their center coincident with the axis of the wire. The number of these lines of force increases with the strength of current flowing through the wire. If instead of being straight the wire is wound about a soft iron core, the strength of the magnetic field will be much greater for a given strength of current flow. For a given kind of iron core the amount of magnetization is the product of current strength and the number of turns divided by the length of the iron core. If the iron core be extended so as to bring the poles close together, as shown in Fig. 22, the amount of magnetization for a given current strength will be still greater. Such an arrangement is called an electro-magnet.

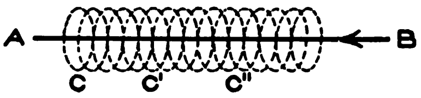


Fig. 21.

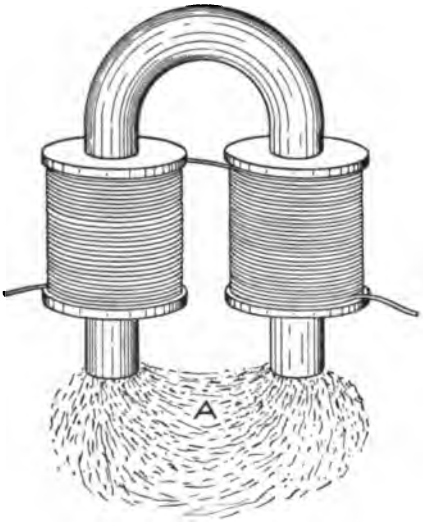


Fig. 22.

If a closed conductor be made to revolve in the field of this magnet, so as to cut the lines of force, as shown at A, an E. M. F. will be generated therein and a current will flow. If, again, this conductor be wound in many turns about a soft iron core, the amount of current generated will be greater for a given strength of field, since the number of convolutions are increased, and the magnetic resistance is decreased by the presence of the soft iron armature. Such an arrangement is called a dynamo or generator. Fig. 23 shows the diagram of a dynamo. The two field cores are shown at A and A′, the yoke at B, the pole pieces at C and C′, and the armature at D. The space between the surface of the armature and the pole pieces E and E′ is called the air gap. The field winding is shown at F and F′, while the armature coils are represented by G. H and H′ are the brushes which serve to collect the current from the armature.

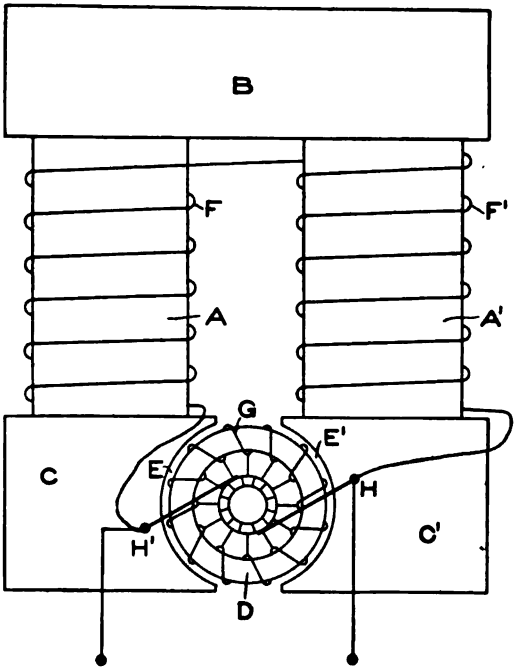


Fig. 23.

There are three ways of winding dynamos. The shunt winding, in which the field winding is of high resistance and shunted around the armature; the series winding, in which the field coils are connected in series with the armature; and a combination of the two, called compound winding, in which a series winding is superimposed upon the shunt winding.

The E. M. F. generated by a dynamo is represented by the product of the strength of field, the number of turns on half of the armature and the speed in turns per second. When a dynamo delivers current, the effective E. M. F. is reduced somewhat by the resistance of the armature. When it is necessary to provide a constant potential from open circuit to full load, it is advisable to use the compound winding, since by this means, as the current out-put increases by passing through the series coils, it assists the shunt coils, increases the magnetic density and tends to keep the E. M. F. constant.

Motors. The construction of a motor is identical with that of a dynamo, but it acts in the opposite way. The current passing through the field and armature turns the latter.

A dynamotor is a combination of a dynamo and motor on one shaft. This machine can be constructed so that the dynamo and motor have independent fields and armatures mounted on the same shaft; or in small machines one field and one armature is provided, and on the armature are two windings, one of which is used for the motor and the other for the dynamo. The commutator of one winding is at one end of the shaft, and that of the other winding is at the other end.

Alternating Current. So far, the generation of current flowing under a constant E. M. F. has been considered. Let us now consider the flow of current under a varying E. M. F. This force may vary in many ways: it may start with a certain maximum value and decrease to zero, or its variations may be irregular and according to no law. The two classes of variable current to be considered here are: one in which the direction of the E. M. F. is periodically reversed; and one in which the E. M. F. is interrupted, but always in the same direction. In the first case, the E. M. F. rises from zero, attains a maximum in one direction, decreases to zero again, and gradually increases to a maximum in the opposite direction. This is called an alternating E. M. F., and the current flowing under its impulse is termed an alternating current. The second kind of variable E. M. F. will be discussed later. With an alternating E. M. F. a thorough knowledge of the law of the variation is necessary.

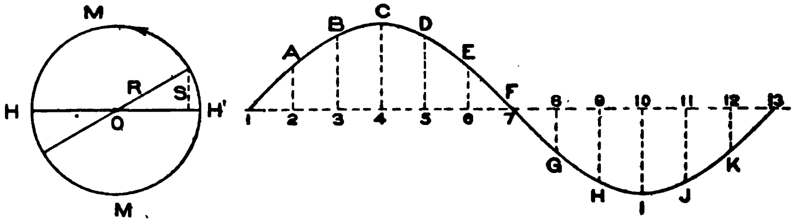


Fig. 24.

Alternating current used for commercial purposes varies according to the law of sines. This is illustrated by Fig. 24. Suppose the circle M is described by the radius R which rotates around the center O, in the direction shown by the arrow head, and from its extremity lines are drawn perpendicular to the horizontal line HH′ as S. The length of these lines will follow the law of sines; that is, for any position of the radius the length of the line dropped from its extremity perpendicular to HH′ is proportional to the sine of the angle that the radius makes with HH′. Starting with R coincident with OH′, the length of S is zero. As the angle between R and OH′ increases, the length of S increases until it equals R for an angle of 90°. As the angle still further increases, the length of S decreases, until at an angle equal to 180°,S is zero again. As R rotates below HH′, S again increases in length, until at an angle equal to 270°,S again equals R. It then decreases, reaching zero again for an angle of 360°, or when R has completed its revolution. On the horizontal line 1—13, equal distances, such as 1—2, 2—3, 3—4, etc., are measured off equal to the angle made by R and HH′ in successive units of time. From these points ordinates are erected which are equal in length to S for the corresponding angle; a line joining the extremities of these lines will be a sine curve. It will be seen that this curve rises from zero at 1 to a maximum at 4, corresponding to a rotation of 90° for R; it then decreases to zero at 180°. From this point it again increases (but in the opposite direction) to a maximum at 10, corresponding to a rotation of 270°, and again decreases to zero at 13, corresponding to a rotation of 360°. The current impelled by this E. M. F. will also follow the sine law. and will vary in the same manner.

An Induction Coil may be defined as that piece of apparatus which transforms a variable current into an alternating current. As it plays an important part in the art of telephony it should be thoroughly understood. The induction coil is somewhat similar to the transformer used for electric lighting and power; but it has its distinctive features. It is a well known fact that when a current starts to flow through the primary winding of an induction coil it sets up a magnetic field in the iron core. If the instant the current first reaches the winding is considered, it will be seen that the magnetic field begins to increase in density. In so doing it sets up a counter E. M. F. in the remaining turns, which tends to retard the passage of the current. As the current reaches the successive turns, this counter E. M. F. is gradually overcome, and the primary current gradually reaches its maximum value. Again, as the primary current begins to decrease a similar counter E. M. F. is set up which tends to retard the decrease. The effect of this magnetic lag or reluctance is to retard the increase and decrease of the primary current, and therefore to change the shape of the alternating current wave induced in the secondary winding.

As will be seen later, it is of the utmost importance that the variation of the primary and the secondary currents should be in harmony with each other and with the sonorous vibrations that are to be reproduced. The induction coil should be designed in such a manner that this condition may exist. It is also evident that the magnetic lag is considerably influenced by the mass and arrangement of the iron core. If in designing a coil it were only necessary to get induced currents in the secondary whose waves were in harmony with those of the original sonorous vibrations, the best results would be obtained with a coil constructed without an iron core. The difference between the permeability of the air and soft iron is so marked that what is gained in clearness of reproduction would be lost by the weakening of the magnetic field, and therefore the induced currents in the secondary. A compromise must therefore be made between weakening the field and strengthening it at the expense of clearness. The closed iron magnetic circuit is therefore discarded and a straight magnetic core made of a bundle of soft-iron wires is substituted. The design of induction coils for telephony has not been reduced to such an exact science as the design of the transformer. However, much has been accomplished by experiment.

Historical. Probably the first mention of the transmission of speech to a distance is that of Robert Hooke, when in 1667 he described how, by the aid of a tightly drawn string, he could transmit sound to a very great distance. The distance over which he propagated sound is not mentioned; but those who are familiar with the lover's telephone, to which Robert Hooke's apparatus no doubt bore a great resemblance, will probably limit the distance to a little over 100 feet. In 1868 Philip Reis, of Friedrichsdorf, Germany, invented an apparatus which, by the aid of the electric current, would transmit sound to a distance. He called it the *Telephon.* In 1876,patent specifications were filed simultaneously at Washington by Alexander Graham Bell and Elisha Gray, and in February of that year the patent was granted to Bell by the United States of America for a speaking telephone. The question of priority between these two inventors was made the subject of a law suit, which ended in a compromise; one company buying out the patents of both.

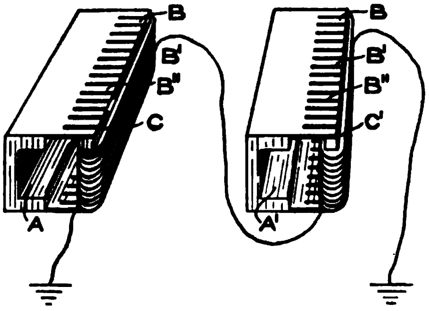


Fig. 25.

The Bell telephone, as first made, consisted of two permanent magnets, of the form shown at A and A′ in Fig. 25, to each of which was attached a harp of steel rods, B, B′, B″, etc. Between the poles of each permanent magnet was an electro-magnet C C′; one terminal of each coil being connected together, while the other terminals were grounded. When the rods of the harp attached to A were made to vibrate the magnetic field of the electro-magnet was disturbed, and currents were thereby induced in its coil. These currents, flowing through the coil of the second magnet caused its field to fluctuate, with the result that the harp attached to A′ was made to vibrate. The vibrations of the second harp were in unison with those of the first, and the amplitude of the vibrations of the first, determined the amplitude of the vibrations of the second; because the strength of the induced currents depended upon the amplitude of the vibrations of the first harp, while the amplitude of the vibrations of the second harp depended upon the strength of the induced currents. While this instrument was useful in proving that sound could be produced at a distance, by means of the electric current, it was useless as a means of transmitting speech.

The second form adopted by Bell is shown in Fig. 26. In this there was an electro-magnet A through which a current was made to flow. Attached to a membrane of goldbeater's skin B, was a piece of soft iron C which acted as an armature, the membrane allowing it to vibrate in front of the pole of the electro-magnet. The receiver was constructed as shown in Fig. 27, in which A represents a vertical electro-magnet enclosed in a soft-iron tube, to which is tightly screwed at one edge an armature B of thin sheet iron. The transmitter was constructed to transmit articulate speech, since the vibrations of the soft-iron armature were in unison with those of the membrane, which in turn, were in unison with those of the voice. The receiver also was capable of giving out articulate speech. In this form of apparatus a battery of cells was placed in the circuit of each electro-magnet.

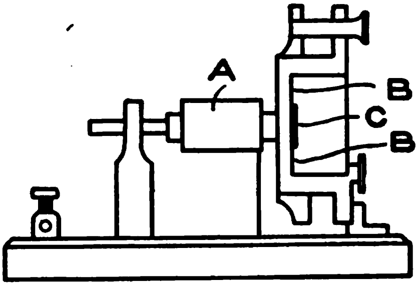


Fig. 26.

The instrument, however, was further modified into the form shown in Fig. 28. It consisted of a permanent magnet of the horse-shoe type, to the poles of which were attached two coils B of fine wire. The thin soft-iron diaphragm was mounted on a separate block as shown at C. Through the opposite side of this block a hole was bored, and a mouthpiece D fitted. The use of the permanent magnet rendered the battery unnecessary. Thus the first practical telephone was produced.

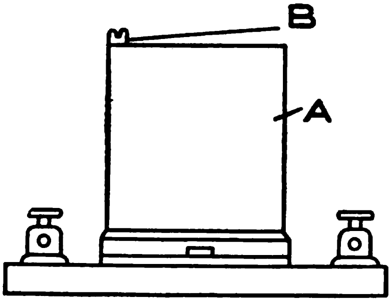


Fig. 27.

The next step in the change of the instrument was to mount both the diaphragm and the permanent magnet in the same case, so that the whole would be self-contained. The result is shown in Fig. 29. It consisted of a shell A, usually of hard rubber. This shell contained a cavity M at its upper end. Through the center of this shell a permanent magnet F was held in place by the screw I and carried at its upper end the coil E of fine wire. The terminals of this coil were brought down through the two channels G and G′ to the two binding posts H and H′. The soft-iron diaphragm is shown at M; it was held in place by the cap B which is scooped out to form a mouthpiece. It will be seen that the essential parts were all contained within the shell. This instrument is practically the same as the receiver in use to-day.

The principle upon which the Bell receiver operates deserves a more detailed description than has yet been given. In Fig. 30, A and A′ represent two Bell telephones connected by a grounded circuit L. Suppose that the receiver A is to be used to transmit sound to A′. The sound waves impinging upon the diapragm at A cause it to vibrate in unison, which means that the vibration of the diaphragm consists of a fundamental and overtones. The diaphragm so vibrating causes the same vibration in the strength of the field of the permanent magnet; this causes the same phenomenon to occur in the induced current flowing through its coil. The induced current, therefore, consists, as did the original sound, of a fundamental and overtones. This is equivalent to saying that the electrical waves of induced currents consist of a wave, equivalent in frequency to that of the fundamental vibration, and superimposed upon this wave are others whose periods of vibration correspond to the frequencies of the overtones of the original sound.

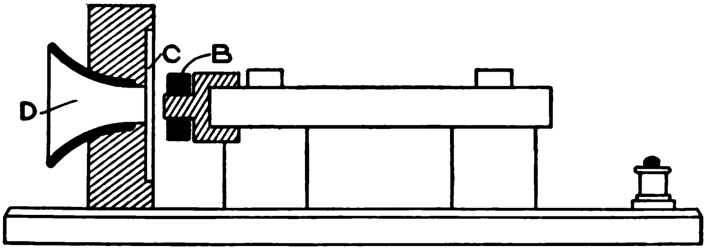


Fig. 28.

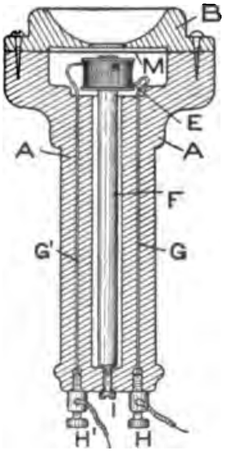


Fig. 29.

These electrical waves travel over the wire and reach the coil on the permanent magnet at A′. Here a reverse process of transformation takes place; there is set up in the magnet a vibrating magnetization, the vibrations consisting of a fundamental whose frequency corresponds to that of the fundamental of the electrical wave, and therefore that of the original sound; while superimposed upon this are other vibrations whose frequencies correspond to the overtones. This fluctuating magnetic field sets up an identical vibration in the diaphragm A′ and therefore in the adjacent air particles. As the air particles at the receiving station are set in the same vibration as those at the transmitting station, the resulting sound is identical. As a matter of fact, the ohmic resistance of the line reduces the amplitude of the electrical waves, so that the resultant sound is not as loud as the original. Additional losses take place at every transformation from sound to magnetic, and from magnetic to electrical energy and the reverse. These losses still further decrease the amplitude of the sound waves at the receiving station, and, therefore, the loudness of the sound.

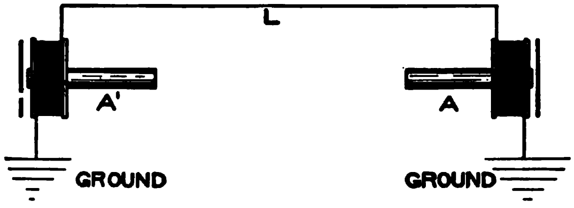


Fig. 30.

The self induction of the line and its static capacity tend to distort the form of the electrical wave so that the resultant sound wave is not identical with the original. These points, however, are of no importance in the present discussion and will be treated later.

Although this explanation of the operation of the telephone is accepted by most engineers as a good working theory, it has been rejected by some scientists on the ground that the currents induced in the coil are too feeble to cause a vibration of the diaphragm as a whole. They contend that the induced currents in the coil cause a vibration among the molecules of the iron core, which in turn causes a vibration among the molecules of the diaphragm; and that it is these molecular vibrations that cause the sonorous air vibrations and not the vibration of the diaphragm as a whole. In support of this theory Ader constructed a receiver without a membrane; and Antoine Bregnet replaced the thin diaphragm by one whose thickness was 14 centimeters. However, whether it be the vibrations of the diaphragm as a whole, or only those of its molecules, has no direct bearing on the theory of operation already described. To show the extreme sensitiveness of the receiver, W. H. Preece made one respond to a current which was .000,000,000,000,6 ampere, which is equivalent to six ten thousand millionths of a milliampere.

The stress existing between the poles of the permanent magnet and the soft-iron diaphragm, will be seen to vary as the square of the intensity of the magnetic force. Let the intensity of the permanent field be denoted by S and the amplitude of the undulations of the magnetic force by s. Then the stress between the poles and diaphragm is proportional to S^2, and the range of variation of the magnetic force is equal to $2s$. The magnetic force therefore varies from $S—s$ at a minimum to $S+s$ at a maximum; and the stress varies from $(S—s)^2$ to $(S+s)^2$. The range of variation is therefore $4sS$, which means that it is proportional to the product of the permanent into the undulating field.

Now the vibrations of the diaphragm are proportional to the varying stress upon it, hence in order to get the best results, the variation in stress must be as great as possible. The above statements show that this result is obtained by making the permanent field very strong. A limit is reached, however, when the permanent field is made so strong that the resultant stress causes the diaphragm to lose its elasticity. Secondly, when the permanent field is greatly in excess, the variations cease to be appreciable. Ordinarily S is greater than s. If $S=s$ the magnetic force will vary from O to $2s^2$. If the magnetic field be abolished the magnetic force will vary from $—s$ to $+s$, and the stress will vary from s^2 through zero to s^2 again. The result will be a reduction of the distinctness of the articulation.

It will be observed that the only force made use of in operating this form of the telephone is that of the sound waves at the originating station. This force is very small and the resultant forces are therefore of a like magnitude. It became obvious, therefore, that a mechanism must be devised to make use of some greater force than that of the sound waves, if the telephone is to transmit speech successfully over any considerable distance. The instrument invented to perform this work is called the *microphone.*

Microphone. If some mechanism could be devised which would vary the current in harmony with the undulations of the sonorous waves, and this varying current could, through the agency of an induction coil, induce a current in the coil of the receiving telephone, the problem would be solved. In 1877, Edison conceived the idea of utilizing the fact that the resistance of carbon to the flow of the electric current, depends upon the pressure; an increase in pressure producing a decrease in the electric resistance.

The first carbon transmitter was constructed by Edison in 1877, and its present form is that shown in Fig. 31 in which A represents an ebonite mouth piece and B a vibrating plate secured firmly to the frame C. At D is shown a disc of prepared carbon, about the size of a shilling which can be adjusted with respect to the vibrating plate by means of the screw E. Placed on the upper surface of the carbon button, is a small platinum plate with a rounded ivory button, by means of which the vibrations of the plate are communicated to the carbon disc. There are two binding posts MM′, the first being insulated from the metallic frame by the hard-rubber bushing N. Attached to the binding post M is a metallic spring S which bears on the periphery of the insulated ring R. The circuit goes from M through the spring S to R thence to the platinum plate through the carbon disc, to the screw, to the frame and out at the binding post M′.

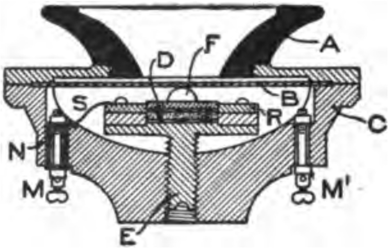
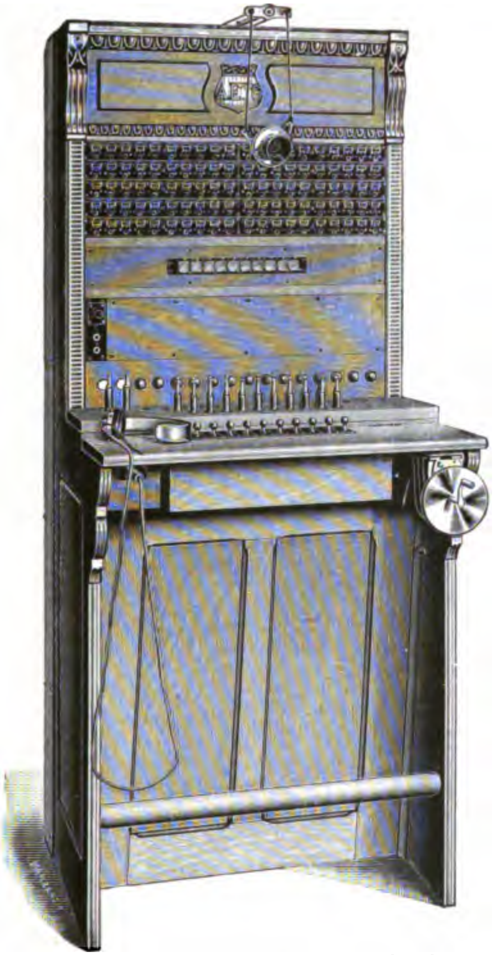


Fig. 31.

It has already been stated that it was necessary to make use of a current from a battery, the current varying in strength in harmony with the sonorous vibrations, to obtain a greater amount of energy for the transmission of sound than is contained in the original sonorous waves. The transmitter just described is a mechanism which performs this work. As the sound waves impinge upon the diaphragm it vibrates in harmony with them causing a vibratory pressure to be exerted through the agency of the ivory button upon the carbon disc. This vibratory pressure on the carbon causes it to offer a vibratory resistance to the passage



AMERICAN BELL-EXPRESS SWITCHBOABD.

American Electric Telephone Co.

of a current of electricity; so that if the terminals of a battery are connected to those of the transmitter, a vibratory or pulsating current will flow through the circuit; and the vibrations of this current will be in harmony with the original sound waves. It will be evident that the sensitiveness of this instrument depends on the ratio existing between the variation in the current and the total value of the current flowing. This ratio in turn depends on the proportion of the resistance of the carbon disc to the total resistance in the circuit.

To illustrate, suppose that the resistance of the carbon disc is 10 ohms, and the amplitude of the variation in the resistance is 5 ohms. Suppose also that the resistance of the circuit exclusive of the carbon disc is 5 ohms. With the transmitter in its normal condition the total resistance in the circuit would be 15 ohms; and if a battery of 2 volts be used the amount of current flow would be $\frac{2}{15}=.133$.

If the resistance of the carbon disc is now decreased to 5 ohms, the total resistance of the circuit becomes 10 ohms, and the amount of current flow is $\frac{2}{10}=.2$. In other words, the current flow has been increased from .133 to .2 or 50 per cent. If on the other hand with all other conditions remaining unchanged, the resistance of the circuit exclusive of the carbon disc be 100 ohms the total resistance of the circuit would vary between 110 and 105 ohms, and the current flow would therefore vary between .0181 and .019 or 5 per cent.

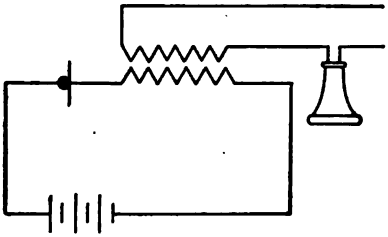


Fig. 32.

When the transmitter was first invented it was to be connected directly to the line causing the exciting current to flow to the other station. The resistance of the circuit was thus added to that of the transmitter, restricting the transmission to very short distances as will be seen from the above. Edison overcame this difficulty by including in the transmitter circuit the primary winding of an induction coil; the secondary winding being connected to the line as shown in Fig. 32. The sensitiveness of the transmitter therefore became independent of the length of the line.

The variable current of the transmitter circuit passing through the primary winding of the induction coil, induces in its secondary winding an alternating current of high tension, the alternations being in harmony with the original sound vibrations. In this manner the transmitter can be successfully used for very long lines.

Hughes Transmitter. In 1878, Professor Hughes devised a transmitter which depended upon the variation in resistance of a loose contact. This instrument was tried in several forms, one of which is shown in Fig. 33. It consisted of a carbon pencil A terminating at a point at each end, which rested in circular depressions in two carbon blocks B B'. These blocks were fastened rigidly to a thin board C and formed the terminals of the circuit.

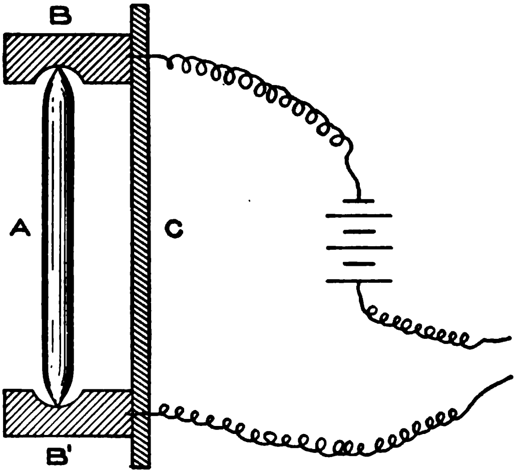


Fig. 33.

This instrument is very sensitive, responding to the slightest vibration; it forms the basis of the transmitter of to-day.

The Blake Transmitter. In Fig. 34 is shown one of the more recent forms of the transmitter, that tried by Blake. This instrument is mounted in a wooden box shown in section at A and consists of an iron ring having two projecting pieces B and B'. Upon the upper projection is fastened an iron angle piece C by means of a brass spring D. The lower end of C rests against the adjusting screw E. Mounted on the iron ring is the diaphragm U which consists of a circular iron disc surrounded by a rubber ring

H stretched over its periphery. It is held in position by two springs M and .M′, Fig. 35, which are fixed to the ring A and press the one directly upon the rubber ring and the other upon the diaphragm itself. At the upper end of the angle piece C are fixed two springs F and G, Fig. 34. Spring F is of thin flexible steel and has at its free end a platinum contact. This free end presses against the center of the diaphragm and the carbon disc K is pressed against it by means of the spring G which is attached to the brass plate holding the disc. The springs F and G form the terminals of the circuit which passes through the carbon disc. By means of the adjusting screw E the pressure of the carbon disc against the diaphragm can be varied. The two springs M and M′ are to keep the diaphragm from singing or to make it "dead beat." This form of transmitter has been very successful in the past, but has been superseded by others which will be described.

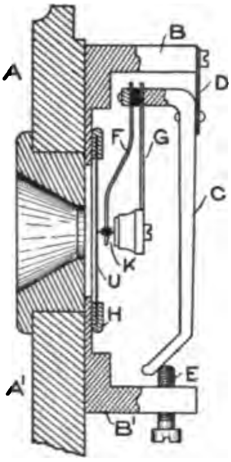


Fig. 34.

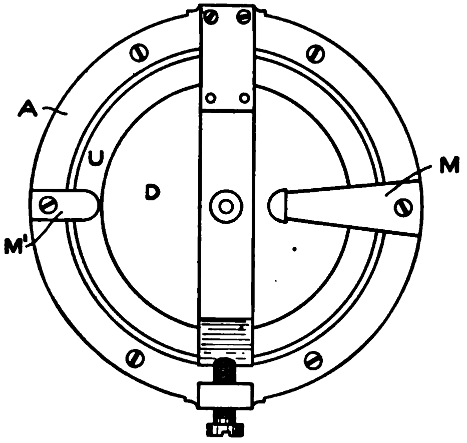


Fig. 35.

Berliner Transmitter. A form of transmitter which is of historic interest is the Berliner transmitter, shown in Fig. 36. It consists of a wooden box A fitted with a screw cap B. On the rim of A is fastened a brass ring C to which is clamped the carbon diaphragm D consisting of a carbon plate which forms one electrode. The carbon block E forms the second electrode, and has in its lower surface three concentric grooves. This block is held in position by the screw F, which has at its upper end a micrometer nut G. The end of this screw, which passes through the carbon block, is turned down to receive a small rubber tube H whose edge rests on the carbon plate and thus damps the vibrations and makes it dead beat. A ring of felt O whose edge rests on the carbon plate, surrounds the carbon block, thus forming a closed chamber, which is filled with carbon granules. A cylindrical shank I is screwed to the cover B and to this a mouth piece J is attached. The advantage of this transmitter is that the diaphragm is always horizontal, with the granules lying above it. The granules are thus prevented from settling down when the instrument is shaken. It is a very efficient transmitter and is used largely in South America.

Hunnings Transmitter. In this transmitter granular carbon is used. The receptacle containing the carbon dust is held in a horizontal position. A metal plate insulated from the frame, but touching the carbon, forms one of the electrodes, while the frame forms the other. Although this transmitter is very sensitive, it is defective on account of the carbon granules packing together. In this condition the mobility of the particles is impaired, and the transmitter rendered useless.

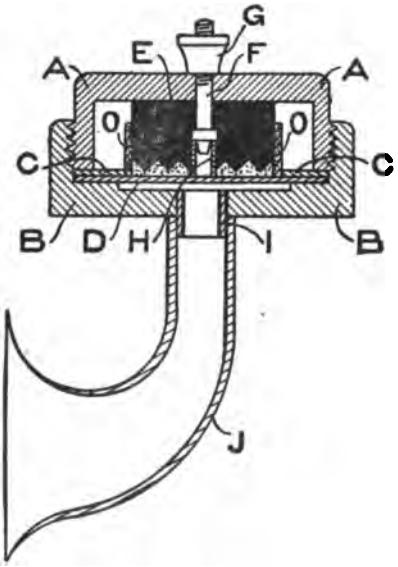


Fig. 36.

Solid-Back Transmitter. The great disadvantage of the granular carbon transmitter is the tendency to "pack;" by this is meant the crowding together of the granules into a compact mass, which greatly reduces the sensitiveness. In fact, when the carbon becomes packed the transmitter is useless. This packing can be readily overcome by striking the side of the transmitter a sharp blow with the hand. This practice however cannot be recommended, for in the hands of a layman it is not conducive to the longevity of the instrument. To reduce the packing to a minimum the solid back was devised. This transmitter is shown in section in Fig. 37; it consists of a thin brass chamber A which is made of ^{1} -inch stock. Securely fastened over the opening of this chamber is a heavier brass disc B having a circular opening in its center, into which is screwed a hard rubber mouth piece C. The diaphragm is a thin metal disc having its edge covered with india rubber and securely fastened to the inner surface of B by means of two springs shown at A and B in Fig. 38. These are identical with the springs shown in connection with the Blake transmitter.

The two electrodes consisting of two finely polished carbon discs E and E′, Fig. 37, are fastened to the inner side of a metallic chamber which consists of two parts. The rear part F is in the form of a circular cup which is firmly held, by means of a pin and set screw, to the brass bridge G. The front part consists of a brass cap H H which is screwed to the front end of F. The front carbon E′ is securely fastened to a brass plate equipped with a pin which fits a hole in the center of the diaphragm, and is held in position by two small check nuts L L′. A ring of mica O O′ has its outer circumference securely held between the brass cap H H and the edge of F, while the inner circumference is clamped securely by the brass nut I. The brass plate and its attached carbon disc are therefore insulated from the other electrode which makes contact with the framework. The chamber P is nearly filled with finely-powdered carbon which closes the circuit between the two plates.

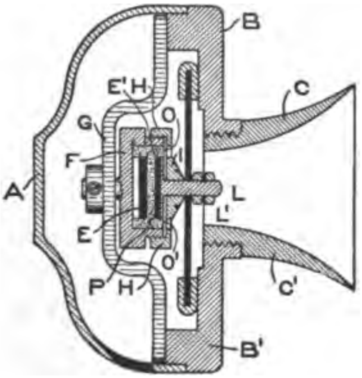


Fig. 37.

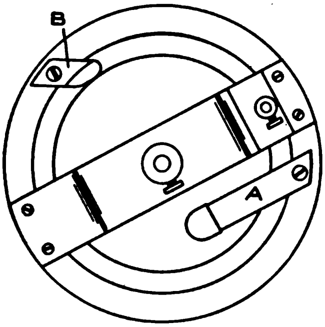


Fig. 38.

A hard-rubber block is securely fastened to one side of the bridge and has a hole drilled into which is fitted a copper bushing. This bushing forms the contact for one side of the circuit, the terminal being held in position in the hole by a small set screw. To a small lug on this bushing is soldered a fine wire, the other end of which is soldered to the brass nut I. The other terminal of the circuit is on the frame of the transmitter. The position of this transmitter being normally as shown in the figure, the carbon granules cannot pack around the carbon plates.

This transmitter has given the best results of any yet devised, and for this reason has superseded all other forms. The Bell Telephone Companies of America use the solid-back transmitters exclusively on metallic lines; while on grounded circuits the Blake transmitter is preferred. The independent, or so-called opposition companies, in America, use a transmitter which is constructed on the principles of the solid-back.

Induction Coil. As the theory of induction coils has already been discussed, let us now take up the special requirements of this form of apparatus when used in connection with the transmitter. It has already been shown that the circuit carrying the transmitter must be so arranged that the resistance of the external portion will be as low as possible. On the other hand the primary winding of the induction coil must have a sufficient number of turns to produce the required magnetic field. It will be seen therefore that the resistance of the winding of the primary coil must be very small in proportion to that of the transmitter. The formula expressing the magnetizing effect of a coil is as follows: $H=1.26\,s\,i\,\mu$ in which H equals the strength of field in lines per square centimeter, s the number of turns of the coil per centimeter length; μ, the permeability of the iron core, and i the current strength in amperes.

From this formula it will be seen that the greater the number of turns and the greater the current strength, the greater will be the strength of the resultant field. It has been shown, however, that the resistance of the coil is limited by that of the transmitter, and therefore the number of turns of the coil is limited by the same factor. Since the quantity s cannot be increased at will, the only way to increase H is by making i as large as possible; this is done by increasing the number of cells used on the circuit. The value of the quantity *i* has its limitations inasmuch as excessively large currents tend to heat the carbon of the transmitter and throw it out of adjustment.

By trial the following proportions have been found to give the best results: In the Blake transmitter the resistance of the primary coil is 1.050 ohms and the E. M. F. used is about 3.2 volts. In the solid-back transmitter, which is capable of carrying a heavier current than the Blake, the resistance of the primary coil is cut down to about ½ ohm. The potential used with this class of instrument is usually about 4 volts. The resistance of the solid-back transmitter under normal conditions is about 10 ohms, but is often as high as 30 ohms during use. The current density passing through the transmitter is about .25 to .3 ampere. The mechanical construction of the induction coil depends upon the shape and size of the instrument in which it is to be used; this will be discussed later.

An account of some of the more important tests will now be given. The results are those of a series of tests made by the Swiss government on ten different induction coils; the Blake transmitter being taken as the standard instrument. The experiments were made on five working circuits ranging in length from .5 to 107.4 kilometers in length. The induction coil used as a standard of comparison was of American manufacture; with the primary coil having a resistance of 1.05 ohms and the secondary a resistance of 180 ohms. The dimensions of the coils tested are given in the following table:

Number of Coil.	Number of Convolutions	Diam. of Wire. m. m.	Resistance ohms.	Number of Convolutions.	Diam. of Wire.	Resistance ohms.
1	61	.5	.25	1956	.15	100
2	62	.5	.25	3191	.15	180
3	62	.5	.25	4080	.15	250
4	116	.5	.50	3952	.15	250
5	230	.5	1.00	3865	.15	250
6	232	.5	1.20	4420	.15	300
7	295	.5	1.50	4278	.15	300
8	368	.5	2.00	4735	.15	350
9	368	.75	1.17	4735	.30	130.2
10	1350	.5	10 00	3950	.15	400

By means of a suitable switch any one of the above coils could be instantly cut into circuit at any time during the test so that a comparison could be made with the standard in a short enough time to enable the tester to retain the original impression. In this manner each coil was compared with the standard. The intensity and clearness of the standard coil is taken as one. The results of the ten coils are shown in the following table:

INDUCTION COIL.

Length in Kilometers.	1	2	3	4	5	6	7	8	9	10	
.5	.3	.7	.9	1.5	1.3	1.5	1.3	1.3	1.7	.3	Intensity
	.9	.9	.9	1.3	1.0	.9	.9	1.0	1.0	.3	Clearness.
61.6	.9	1.0	1.0	1.7	1.3	1.6	1.5	1.5	1.6	.3	
	1.0	1.1	1.3	1.5	1.2	.9	.9	.9	.9	.5	
79.1	.3	.9	.9	1.3	1.1	1.7	1.1	1.1	1.7	.3	
	.7	1.0	1.0	1.5	1.3	1.3	1.1	1.0	1.4	.3	
85.3	.7	1.0	.9	1.3	1.3	1.7	1.5	1.5	1,6	.3	
	.8	1.3	1.3	1.5	1.5	1.6	1.4	1.4	1.6	.4	
107.4	.2	.7	.6	1.2	1.0	1.5	1.6	1.6	1.7	.3	
	.9	1.0	1.0	1.5	1.3	1.5	1.3	1.2	1.3	.1	

In the above table there are two sets of figures for each coil, opposite every distance. The figures in the upper row denote the intensity; those in the second row, the clearness. The table shows that the same induction coil does not give equally good results on all lines. For example, coil No. 1 has an intensity of .3 on a line .5 kilometers long; while on a line 61.6 kilometers long this figure rises to .9, almost equalling the standard. On the next longer line, this quality falls to .3, but rises again to .7 on the 85.3 kilometer line. On the longest line it again falls to .2. Coil No. 2 acts more uniformly in the point of clearness, being about equal to the standard on all but the 85.3 kilometer line, where it rises to 1.3. On the whole, coils No. 4 and No. 9 give the best results for general use, and conform in point of make up to the best practice of to-day.

Complete Telephone. Thus far we have discussed only the two essential features of the telephone instrument—the transmitter, or that which converts the sonorous vibrations into electrical vibrations; and the receiver, or that which converts the electrical vibrations back into sonorous vibrations. Let us now take up the telephone instrument, which makes use of these two essential principles, together with some auxiliary features.

In addition to transmitting speech, a complete telephone instrument must also be able to convey some sort of signal from one end of the line to the other, in order to inform the party at the distant end that attention is desired; it must also be able to *receive* a signal thus transmitted from the distant end. In all cases the bell is used as a means of receiving the signal, while a small hand generator is used to transmit the signal to the distant end. The method of connecting the bell and the generator has given rise to two distinct classes of instruments, each possessing distinctive features. These two classes are called the *series* telephone and the *bridging* telephone.

The method of wiring up a series instrument is shown in Fig. 39, in which the line enters at A, and terminates at a peculiar shaped switch C. This switch is so constructed that it moves in a vertical direction and when in its upper position makes contact with the two points D and E. When depressed, the contact with D and E is opened and that with F closed. Assuming the switch to be in the latter position (closed) the circuit passes through the contact point F to the generator and B bell coils K and thence through the binding post A′ to the other side of the line in the case of a metallic circuit or to ground at G when the earth is used as a return. It will be seen that under these conditions the generator B and bell K are in series on the line. The generator B is equipped with a shunt L which is closed when the generator is out of use, thereby cutting the resistance of the generator armature winding out of the circuit. When the handle of the generator armature is revolved this shunt is automatically opened so that the generator is ready for use.

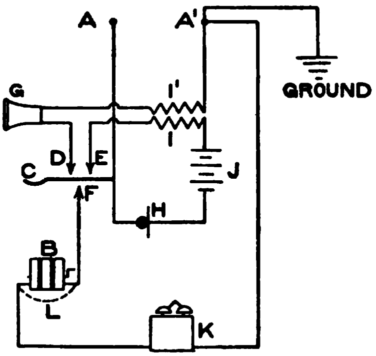


Fig. 39.

Assume a line to be equipped at either end with a telephone wired as shown in Fig. 39. If a call is sent from the distant end by revolving the armature of the generator at that point, the alternating current thus produced arrives at the binding post A, passes through the bell K (by the route already shown) to the post A′ and returns. The bell is therefore sounded. Should the signal be sent from this end,the armature of the generator is revolved, the shunt L being opened thereby and the current flows out on the line at A. It returns either metallic or through the earth to A′, thence through the bell K to the contact F, through the switch C back to A.

When conversation is desired the switch is moved to its upper position opening the contact at F and closing those at D and E. The circuit from A passing through the switch C now follows the path from the contact D through the receiver G and the secondary winding I′ of the induction coil back to A′. The circuit including the transmitter passes from the battery J through the primary winding I of the induction coil to the contact E, thence through the switch C to the transmitter H returning to the opposite side of the battery. The circuit including the bell is open at F. Assuming that the switch of the telephone at the distant end of the line is similarly adjusted, conversation is possible. Suppose that the telephone at this end be used to transmit. The sonorous vibrations impinging on the diaphragm of the transmitter H cause a variable current to flow through the circuit in the manner described above. This induces a current in the secondary winding I′ which, flowing out on the line, actuates the receiver at the distant end. If the instrument at the distant end be used to transmit, the induced current generated at that end flows over the line and actuates the receiver at this end.

An examination of the circuit will show that whether the instrument at this end be used to transmit or to receive, the induced current passes through the receiver. The same is true of the telephone at the distant end. The sound produced in the receiver of a telephone (when that telephone is used to transmit) is called a *side tone.* Allusion will be made to this later on. Referring to the switch C it will be seen that it is to close the bell circuit and open the receiver and transmitter circuits when the instrument is not in use. By this means the circuit containing the transmitter battery J is opened during this period, the current ceases to flow and the life of the battery is therefore prolonged. On the other hand, the bell and the generator are in circuit ready to receive or transmit a signal. It is absolutely necessary to keep the bell out of the talking circuit because its resistance and impedance would so cut down the induced current as to seriously impair the efficiency of transmission. This form of instrument was designed at the time when grounded circuits were almost universally used. It served its purpose admirably. Even with the advent of the metallic circuit it was still retained, and up to the present time is not altogether discarded.

The three pieces of equipment that have not yet been described in detail are the generator, the bell and the switch.

The Generator is shown in Fig. 40 and consists of a permanent magnetic circuit made up of four horse-shoe magnets, A, A′, A″ and A‴ fastened together by the three bolts B, B′ and B″. The pole pieces consist of two iron castings, the edge of one of which is shown at C. The armature shaft is supported on two cast-brass bearings which are screwed to the ends of the pole pieces, one of which is seen at D. At the distant end the armature shaft is equipped with a pinion I, which meshes with a spur gear H. This gear is securely fastened to a crank shaft F, which rests in two strut bearings, one of which is shown at G. The crank is shown at E. A prolongation of the armature shaft J makes contact with the spring K when the crank is not turned. This contact forms

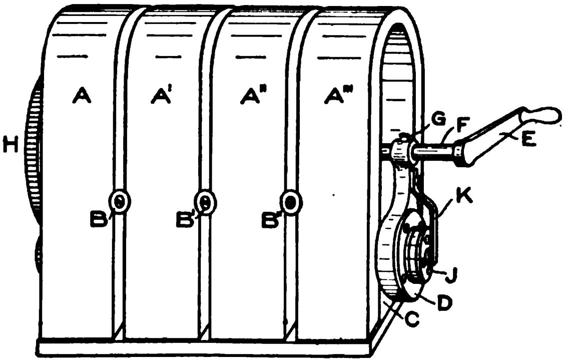


Fig. 40.

one of the terminals of the shunt, the other terminal being permanently connected to the other terminal of the armature winding. When the crank is revolved a concealed spring draws the point J away from K, breaking the contact. One terminal of the armature winding is insulated from the armature shaft, while the opposite terminal is electrically connected to it; the return circuit being made through the shaft and frame of the generator.

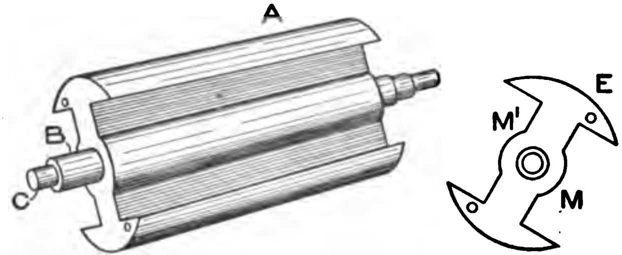


Fig. 41.

The construction of the armature is shown in Fig. 41, in which the armature core is shown at A. It is made up of thin sheets of soft iron, one of which is seen at E. The armature shaft is shown at B and the insulated contact that automatically closes and opens at C. The coil of the armature is laid in the slots M and M′ and is wound end for end. One terminal of the coil is electrically connected to the contact point C, while the other terminal is connected to the shaft B. Fig. 42 shows the end of the armature shaft carrying the pinion A. The spring C automatically makes and breaks the shunt circuit; the spur gear is shown at B.

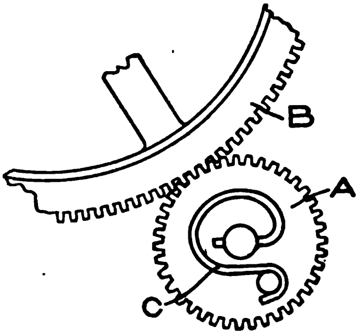


Fig. 42.

The Bell. In a series instrument, the bell is wound to a resistance of 80 ohms. It is made up of a two-pole electro-magnet with the armature pivoted in the center so that it vibrates in front of the two poles. There is nothing peculiar about its design with the exception that it is given a bias by means of a permanent magnet placed above the armature and at a variable distance from it. The action of this magnet is to attract one side of the armature away from the pole of the electro-magnet, so that it always assumes that position when the bell is not in use. By adjusting the distance of the permanent magnet from the armature, the degree of bias can be regulated. If this distance is too short, the alternating field of the electro-magnet will not be strong enough to overcome its pull and the bell will not ring. The clapper of the bell is a small steel ball placed at the end of a steel wire, the other end of which is fastened to the center of the armature, so that the clapper vibrates with the armature. Two gong-shaped bells are placed on opposite sides of the clapper so that each stroke produces a ring. In Fig. 43 is shown a magneto box designed to hold the generator, bell and switch; the bell coils are shown at A A′, the vibrating armature at B and the permanent magnet to produce the bias at C. This apparatus is mounted on the inside of the door of the box as shown. The bells project from the outside.

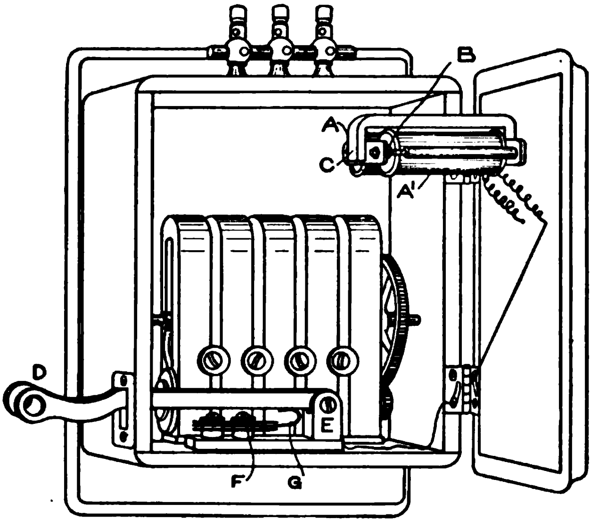


Fig. 43.

The Switch D is pivoted at E. When the instrument is not in use the receiver is hung on the hook D, and its weight brings the switch down to its lowest position. Upon the receiver being removed, the spring G pushes the switch up again; the contact points are shown at F. In the position shown the switch makes contact with the two upper points, the lower one remaining open.

The Receiver. It has been said that the receiver in use to-day is practically the same as that of the original Bell telephone already described; but this is true only in general because several important improvements have been made. Receivers may be divided into two classes: *single-pole* and *bi-polar.* Bi-polar receivers are more sensitive and are displacing the other type. One of these is shown in Fig. 44. It consists of a hard-rubber shell shown at G G′, one end of which is enlarged to support the binding posts D and D′, and also to hold the screw B, which secures the permanent horse-shoe magnet A made of hard steel. Fastened to the poles of this magnet are two soft-iron cores E E′, each one surrounded by the exciting coil. From the two binding posts two heavy copper wires C C′ lead to the terminals of the electro-magnetic coils I I′. The diaphragm O is held in place by the hard-rubber cap F.

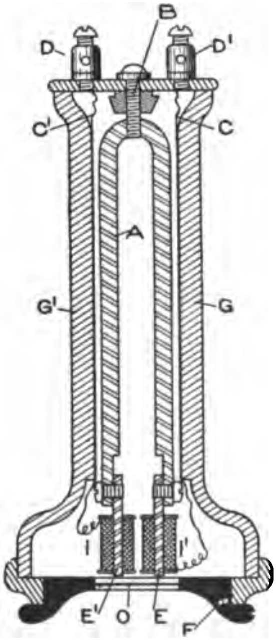


Fig. 44

In addition to the design of the receiver, considerable experimenting has been done to determine the best materials. For the diaphragm, soft iron has been found to be the most suitable on account of its susceptibility to magnet influences. As to size, it has been found that a diameter of 2.4 inches gives the best results. The flexibility increases with the area of the diaphragm. But while a certain degree of flexibility is desirable in order that the whole diaphragm may be thrown into vibration, an excess will cause the free vibrations to become too marked, thereby reducing the clearness. To obtain the greatest efficiency, the thickness of the diaphragm should be from .008 to .012 inch. It should be perfectly homogeneous, and securely held about the rim. A thin layer of varnish is used to prevent the metal from rusting. The inner surface of the diaphragm should not make mechanical contact with the poles of the receiver; there should be an air space of about $\frac{1}{32}$ inch in order that the vibrations may not cause the metal to strike the poles. The resistance of the coils, varies between 75 ohms and 135 ohms, and equally good results have been obtained with the one as with the other. Most receivers now in use have a resistance which varies between 75 and 80 ohms.

The single pole receiver is similar to that shown in Fig. 44. For operators, a receiver has been designed to be fastened on the head by a steel spring. This type is called a *head receiver.* One of these is shown in Fig. 45. It will be seen that the body of the receiver is flat, due to a shortening of the magnetic circuit. The steel spring clip is made in one piece, as shown in Fig. 45, or a double piece as in Fig. 46. This receiver is the same as that already described, and is usually of the bi-polar type.

Let us now consider the form of the coils placed upon the pole pieces. The induced currents passing through these coils, which for convenience sake may be called the *talking currents*, are very small in intensity, varying between .0001 to .00001 ampere; as a result the magnetic influences produced thereby are also very weak. Therefore to make them effective, the coil windings must be placed as near the iron cores as possible. Only very fine silk-covered wire is permissible—that having a diameter of from .004 to .006 inch. About 710 turns are used in each coil—a total of 1,420 turns. In a single pole receiver, the 1,420 turns are wound on one coil. For a single-pole receiver, the shape of the coil is circular, while those of the bi-polar receiver are elliptical.

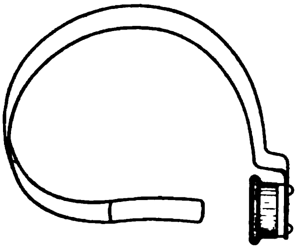


Fig. 45.

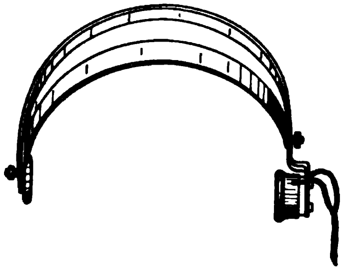


Fig. 46.

The Bridging Telephone. Let A and B, Fig. 47, represent two telephone stations on a line. Assume both of these stations equipped with series bells. If now it is desired to connect an additional telephone to the line, the difficulty will at once become apparent. If the third station be cut in as shown at C the three bells will be bridged across the line. With the low resistance to which the series bells is wound (80 ohms) the third bell would shunt so much current from the other two that they would ring very faintly. A more serious condition: during conversation between any two of the stations, the bell of the third one would still be bridged across the line. The result would be that so much of the talking current would be shunted by the bell that conversation would be possible only on lines of a few hundred feet in length. If more telephones were added to the line, the effect would be still more marked. On a very short line it might be possible to operate three telephones wired in this way, but it would be impossible to operate a greater number. Even with the best conditions the results with the three telephones would be far from satisfactory.

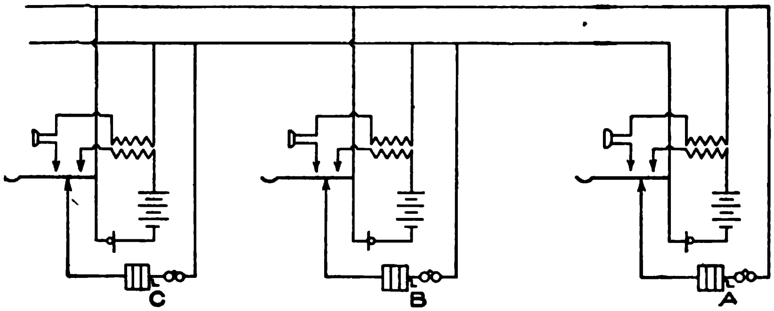
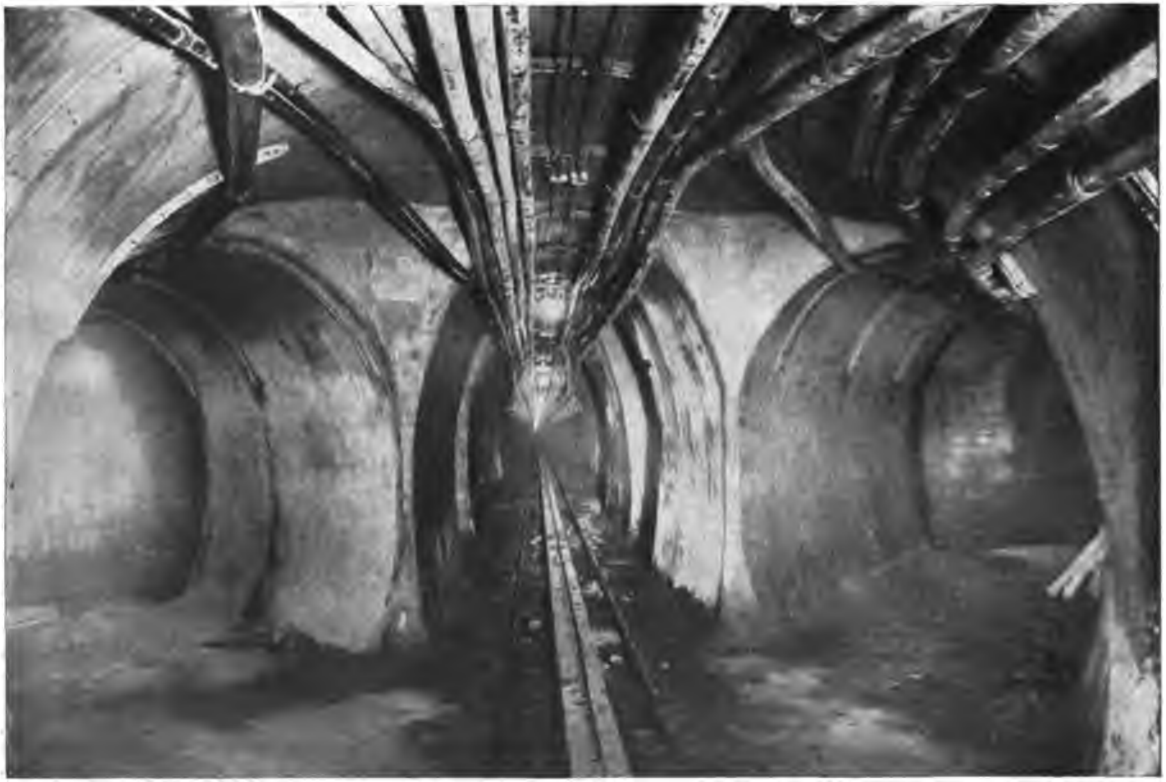


Fig. 47.

To make the use of more than two telephones on a line possible, and to overcome the difficulties described, the *bridging bell* was invented by Mr. J. J. Carty, Chief Engineer of the New York Telephone Company. The principle of this bell is best explained by quoting from the patent specifications, which call for a "bell of high impedance, permanently bridged across the telephone circuit." The bell having a high impedance, does not shunt out an appreciable amount of current. The original bridging bell was wound to a resistance of 1,000 ohms, and to-day this figure is the standard.

The number of turns on the bell coils is much greater than with the series bells, therefore the current density necessary to produce the ringing is much less than with the other type. Again, the



VIEW OF THE TUNNELS OF THE CHICAGO SUBWAY COMPANY.

Showing Manner of Hanging Automatic Telephone Cables.

impedance of the bell coils is so high, compared with that of the circuit through the telephone receivers, that the amount of talking current shunted is inappreciable.

The method of connecting up the telephone with the bridging bell is shown in Fig. 48, in which A represents the generator, B the bell coils, H the receiver, C the secondary winding of the induction coil, D the primary winding, E the transmitter battery, F the transmitter and G the hook switch. It will be seen that the generator A together with the bell coils B are permanently bridged across the line. The generator armature is provided with an automatic switch, which leaves the armature coils on open circuit during the time that the generator is out of use. Upon turning the crank the coil is cut into circuit. The only difference between the wiring of this telephone and that with the series bell, is in the switch. It will be observed that with the bridging bell the hook switch is not provided with a lower contact. The only contacts are those marked 1 and 2, which form the circuit for the receiver and the transmitter. As in the case of the telephone equipped with the series bell, these two contacts are opened when the switch moves to its lowest position, and are again closed when the switch returns to its highest position. With this form three or more can be connected to a line without interfering with the transmission. The greatest number of telephones of this type that can be successfully operated on one line will be treated more in detail later.

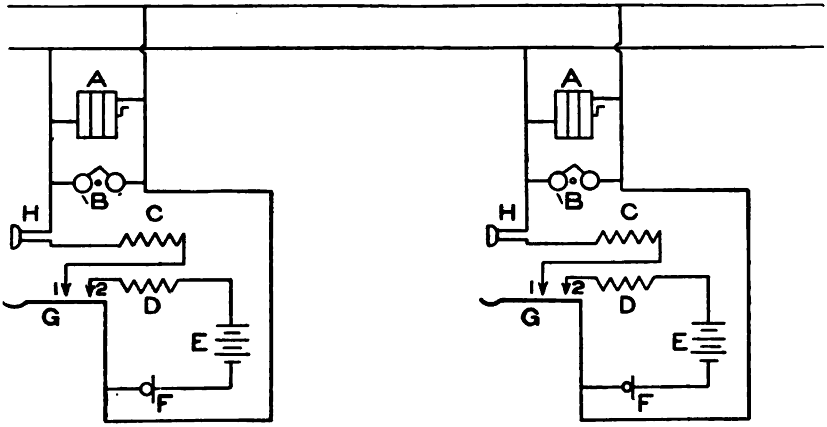


Fig. 48.

While the essential parts of a telephone remain unchanged, the method of assembly or mechanical construction differs considerably in different types of the instrument. In this respect telephone instruments may be divided into four classes: The framework of the **desk cabinet telephone** is made up in the form of a desk, so that the person using it may sit down and write. With the **wall cabinet telephone,** the subscriber stands up, but also has a surface to write on. These two types are so constructed that a cabinet is provided for the reception of the battery. With **wall telephones** the transmitter, induction coil, bell and generator are mounted upon a back board to fasten on the wall at any desired height. A small shelf is usually provided for writing. The transmitter of the **desk stand telephone** is mounted on a metallic arm provided with the hook switch. This stand is portable and constructed to set on a desk or table. The box containing the bell and generator is usually mounted separately as is also the induction coil.

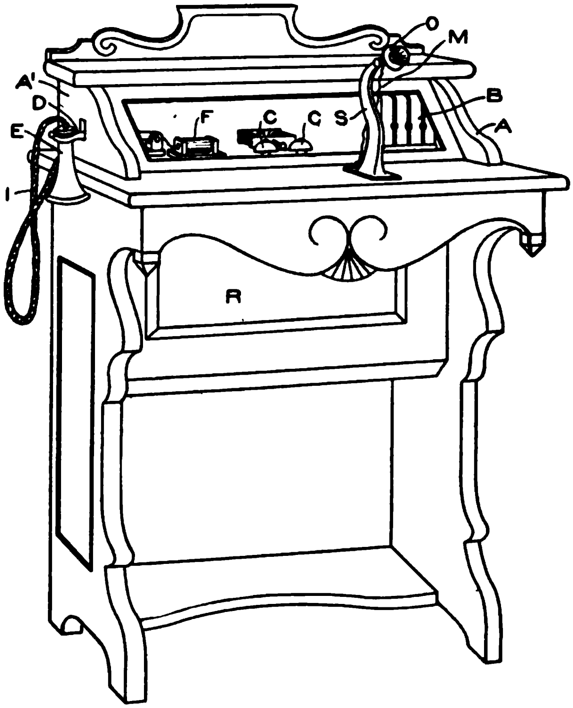


Fig. 49.

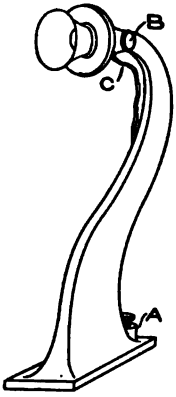


Fig. 50.

In Fig. 49 will be seen an illustration of a desk cabinet set, of one of the most approved types. It consists of a desk-like structure, upon which is mounted a cabinet A A′ equipped with a glass front through which are seen the generator B, the bells C and the induction coil F. The switch D has its hook end projecting through a slot in the side of the cabinet; and the pivot end can be seen through the glass cover. The receiver E is seen in its position on the hook, and is connected (by the flexible cord I) to two binding posts, one of which forms the line terminal, and the other the terminal of the secondary winding of the induction coil. This cord is made up of two conductors of fine copper tinsel, thoroughly insulated by close cotton braiding, and together enclosed in a cover of heavy cotton braid. The transmitter which is of the solid-back type is seen at O. It is mounted on a supporting arm S which is fastened to the top of the cabinet. The circuit from the primary winding of the induction coil is made through the flexible cord M, which is constructed of very fine copper strands, insulated with silk and cotton winding and covered with a close heavy silk braiding. The transmitter is fastened to the arm by means of a milled-head screw, so that it can be adjusted to the proper height. The return circuit is through an insulated wire attached to a binding post placed on the foot of the arm. An enlarged view of the arm is shown Fig. 50. The binding post is seen at A and the milled-head screw, for securing the transmitter, at B. The flexible cord is seen at C. The batteries are held in a cabinet, which is closed by a movable door R.

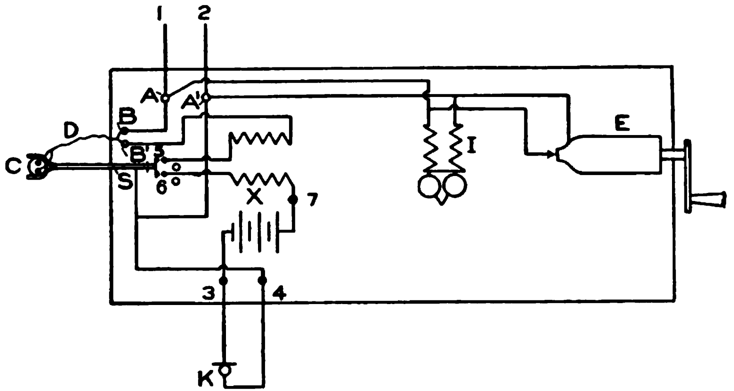


Fig. 51.

The plan of the wiring is shown in Fig. 51. Here the line wires 1 and 2 are run to the binding posts A and A′, A being wired directly to the binding post B. The post A′ is wired directly to the switch S. Ths binding post B′ is wired to the secondary coil, and its other terminal to the contact point 5. The contact point 6 is wired directly to the primary coil, whose other terminal is wired to the binding post 7, thence down to the batteries placed in the cabinet as described, from which the wire comes up to the binding post 3. The flexible cord M, Fig. 49, runs from the post 3 to the transmitter K, the return circuit going to binding post 4, which in turn is wired permanently to the switch S. The receiver is shown at C, and the receiver cord at D. The bell coils I are bridged across the line at A and A′. The generator E is bridged across the bell coils. All permanent wiring is done with No. 19 B & S gauge rubber-covered wire laid in channels.

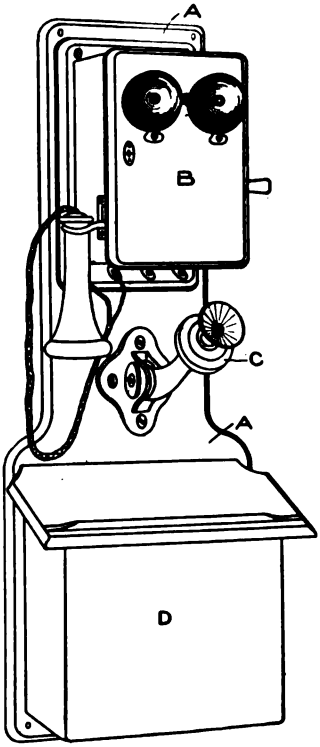


Fig. 52.

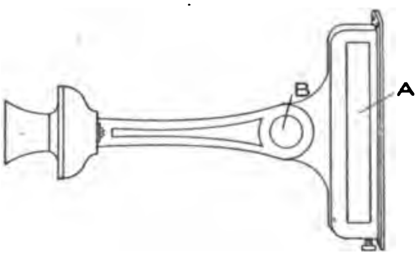


Fig. 53.

The telephone of the wall-cabinet type consists of the same essential features as the desk-cabinet set. The induction coil, generator, bell and switch are mounted in the cabinet which has a glass front. The transmitter arm is of the same type, but shorter than that used on the desk-cabinet sets. The battery cabinet is made in three compartments, one above the other, each one large enough to hold one Fuller battery.

In Fig. 52 is shown a wall set. It consists of a back board

AA upon which are mounted the magneto-bell box B, and the transmitter C with its supporting arm. The bottom third of the back board is flared out to accommodate the battery box D. This box is designed to hold three Leclanche batteries. When Fuller batteries are used, a separate battery box is provided which is placed on the floor. In the instrument shown, the induction coil is mounted in the magneto box; the transmitter arm being merely a support. In Fig. 53 is shown a transmitter arm which has a metallic receptacle A for the induction coil. Both styles of arms are pivoted at B for the adjustment of the height.

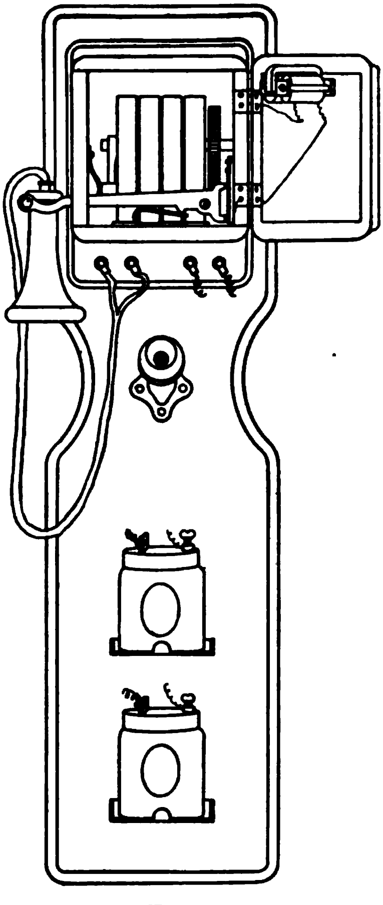


Fig. 54.

Fig. 54 shows a modification of the wall set in which the battery box is so designed that the cells may be placed one above the other. The back board can then be made narrower thus saving wall space. The magneto-generator box is shown in Fig. 43. Fig. 55 shows a slightly modified form which is used by the Bell companies for series telephones. The hook switch A is pivoted at B and its heel is equipped with a platinum point C, which, when the switch is in the upward position, makes a contact with two springs, one of which is seen at D. Beneath the heel of the switch is a hard-rubber block E which presses against the two springs and breaks the contact when the switch is depressed. Beneath the switch is a spring F which presses the hook upward when the receiver is removed. Fastened to the under side of the switch is a small hard-rubber block G which insulates the spring when the switch is at its highest point. Just in front of G is a wedge-shaped projection H having a platinum point which makes contact with F when the switch is at the lowest position, thus closing the bell circuit. At the end of the crank shaft opposite the crank will be seen a small pin I, which, when resting against J, closes the shunt on the armature. Upon revolving the crank, this point is automatically drawn away from J thus opening the circuit. At the top of the box are three binding posts marked L P and L. The two marked L being for the line wires while P is connected to ground, when the instrument is used on a grounded circuit. At the bottom of the box are three pairs of posts, two marked T for the receiver cords; two marked B for the primary circuit and two marked M for the secondary. The wiring is the same as for the series bell. From the switch A projects a german-silver strip S to which is soldered all permanent connections.

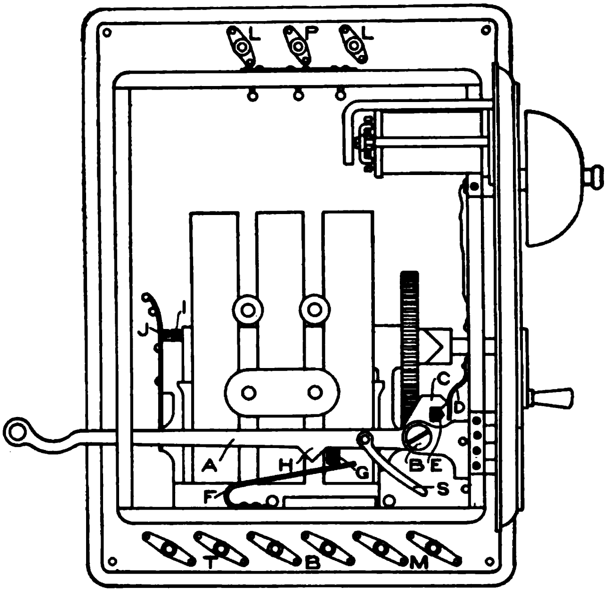


Fig. 55.

In Fig. 56 is shown the form of bridging bell used by the Bell companies. It is made up in the same form as the series bell. It will be observed however that the spring under the switch always makes metallic contact. Since there is no connection on this spring there is no necessity for insulating it from the switch. The pin at the end of the crank shaft remains normally separated from its contact, being automatically closed as the crank is turned. The bell coils on this bell are longer than those shown in Fig. 55. This is for the accommodation of the extra wire. Of the six binding posts on the bottom of the box, two (marked R) are for the receiver cords; one marked P for the primary coil; one marked B for the battery; and two marked S for the secondary coil. Both of thyse magneto boxes are designed for wall sets where the induction coil is in the transmitter arm.

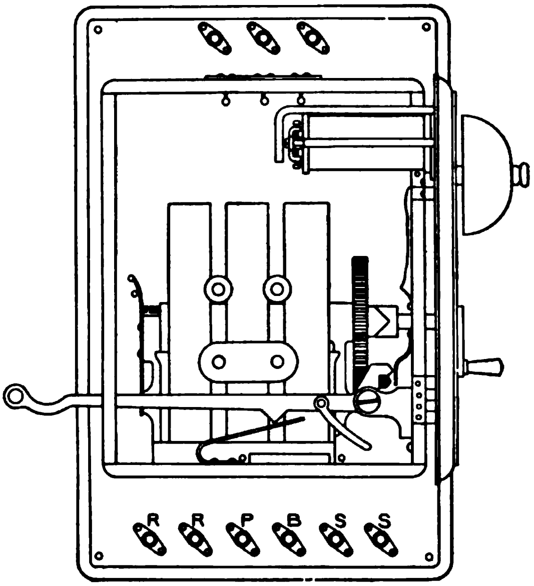


Fig. 56.

In Fig. 57 is shown one of the types of desk-stand sets. The transmitter is supported on a metallic shank A provided with a heavy base B. The shank is hollow and the hook switch passes through a slot, making all connections inside. The receiver cord is shown at D, and makes connections inside of the base. With this style a separate magneto box is used, which may or may not contain the induction coil.

The plan of wiring is shown in Fig. 58 where R and S denote the terminals of the primary and secondary winding of the induction coil respectively; the post between them being dead and used as a connector only. One side of the transmitter circuit is wired to the switch by means of a flexible cord; connection to the other side being made through the frame and the contact 1. The receiver circuit is completed through the flexible cord A to the contact 2. In other respects the circuit is the same as that already described for a bridging bell. This type of telephone is used with either a bridging or series bell.

Special designs are sometimes made to meet requirements. One of these is shown in Fig. 59. It is of the wall type, and the bell, induction coil, generator and accessories are placed in a cabinet, on the door of which is mounted the transmitter arm. The transmitter current is furnished by two dry cells. This is a very compact and convenient form of instrument.

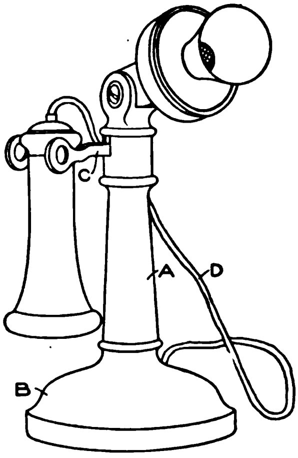


Fig. 57.

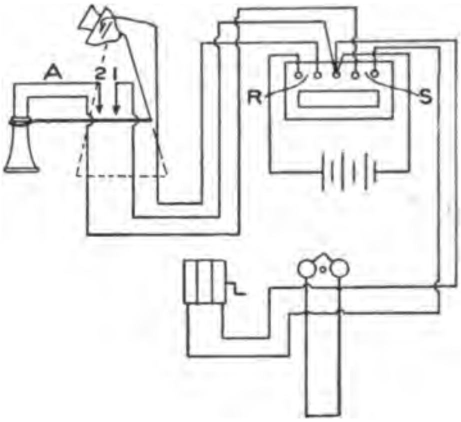


Fig. 58.

Relative Merits of Transmitter Batteries. It must be remembered that the microphone, consisting of the transmitter, battery and induction coil, depends for its operation upon the fluctuation of the current flow in the circuit. For its operation, this fluctuation must be in harmony with the sonorous vibrations. Since any fluctuation of the current produces an induced current on the line, and therefore a corresponding sonorous vibration at the receiving end, it is absolutely necessary for the proper working of this apparatus that the fluctuations be produced solely by the change in resistance of the transmitter. In other words, the battery must give an absolutely constant current and all connections on the circuit must be perfect. Therefore, a cell adapted for a transmitter circuit must give constant E. M. F. In this respect the Gravity, Fuller, Leclanche, Edison-Lalande, and the two types of the dry cell already described are equal when in good condition.

The Gravity battery is the least likely to produce fluctuations in the E. M. F. by getting out of order. If the zinc, however, is allowed to become very dirty from creeping-salt deposit, a fluctuation of the E. M. F. is produced, which renders conversation over very long lines impossible. There are no cases recorded where this effect has been noticed with batteries having oil on the surface.

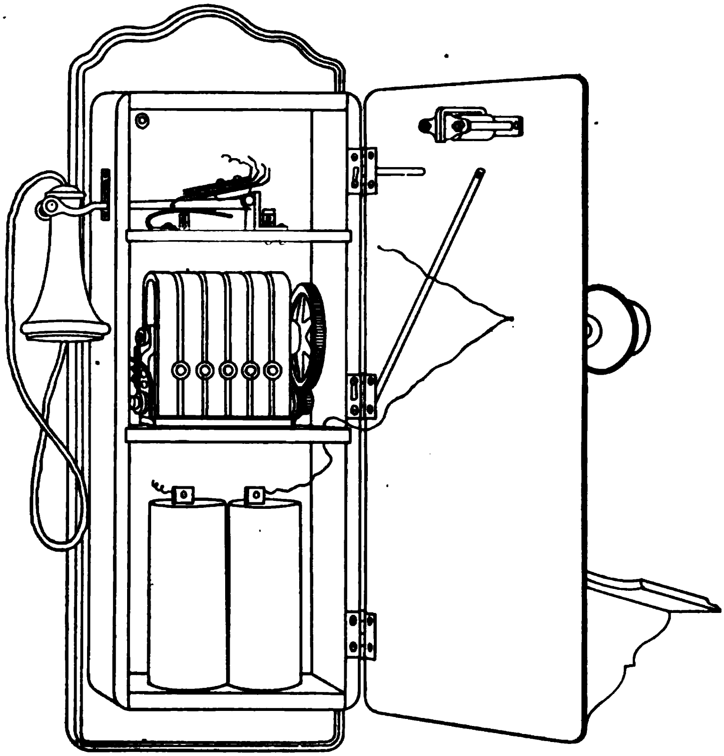


Fig. 59.

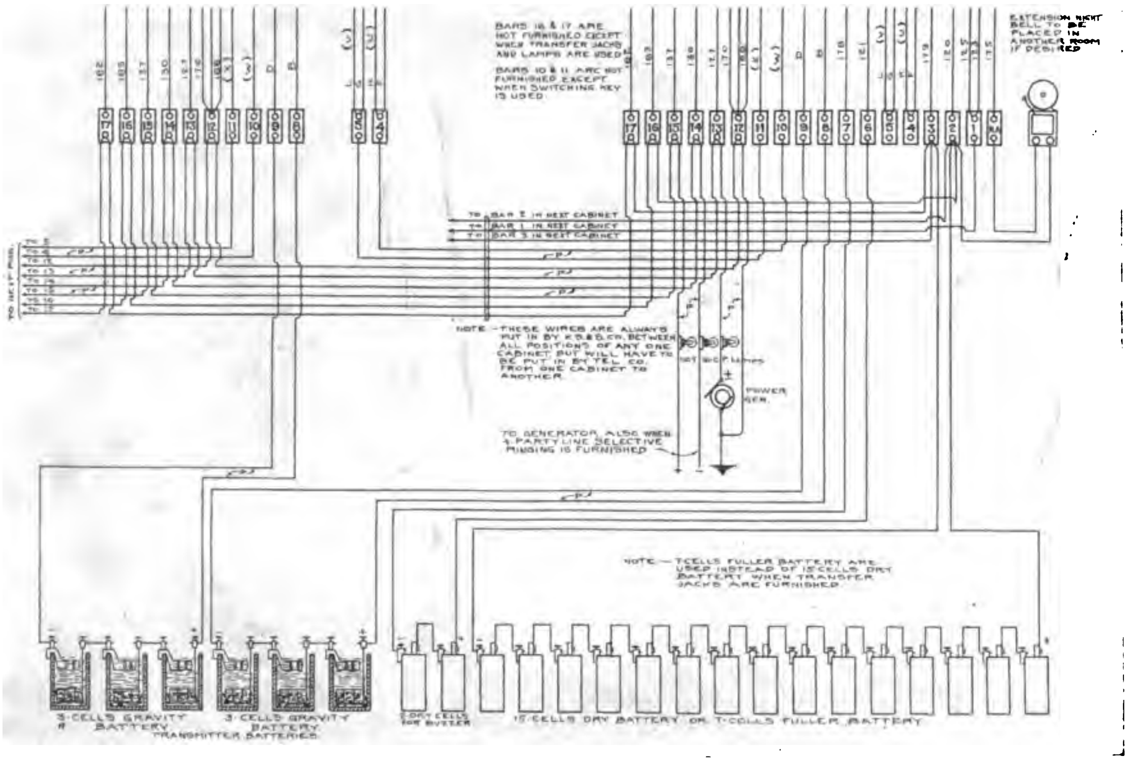
Impurities in the zinc tend rather to retard the creation of zinc sulphate, and therefore lower the E. M. F. of the cell. The principle source of trouble with this type of cell is the collection of dirt on the zinc element, which interferes with the creation of zinc sulphate, thereby reducing the E. M. F. of the cell. The zinc should, therefore, be kept clean.

With the Fuller cell, care must be taken to preserve the amalgamation. To do this a little mercury is placed in the bottom of the porous cup, so that it can always be in contact with the zinc. Should the supply of zinc amalgam give out, severe local action would be set up by the contact of the chromate of potash solution and such impurities as iron and other metals. This local action would set up varying E. M. F.'s which would be in opposition to that of the cell. When the zinc is placed in the porous cup, care should be taken not to bend the copper wire at the edge of the battery cover. If this is done the zinc cannot feed down as it becomes used. The wire should be allowed to extend straight out three or four inches before being bent over. This type of cell becomes exhausted quicker than the Gravity battery, and ordinarily about five renewals a year are required. The zincs must be replaced about two or three times a year.

In the Leclanche battery, the zinc is placed in contact with the active electrolyte, but it is purer than that used in the two cells already described. The zinc is amalgamated when first introduced. As it becomes eaten away, zinc sulphate crystals form, with the result that unless replaced by new, a loud hissing will result.

Dry cells are used only on very short lines, and under these conditions, give fairly good results. The Edison-Laland battery is very seldom used on the transmitter circuit, being reserved for operating signals and other purposes to be described later.

To sum up, the Gravity battery is best adapted where the cost of maintenance and renewal is high. They are used on the operators' transmitter circuit in country and suburban exchanges. For the proper E. M. F. three cells are connected in series. The Fuller battery is best adapted for intermittent work at points near the supplies. Two cells in series are sufficient for ordinary use. The Leclanche battery is used on the transmitter circuit of subscriber telephones in thinly populated districts, where the cost of renewal is high, and the number of long distance connections small. Three cells in series are commonly used. On long distance lines three cells of the Fuller battery are commonly used on the subscribers' telephones.


EXTENSION NIGHT BELL TO BE PLACED IN ANOTHER ROOM IF DESIRED
BARS 16 & 17 ARE NOT FURNISHED EXCEPT WHEN TRANSFER JACKS AND LAMPS ARE USED
BARS 10 & 11 ARE NOT FURNISHED EXCEPT WHEN SWITCHING KEY IS USED
TO BAR 2 IN NEXT CABINET
TO BAR 1 IN NEXT CABINET
TO BAR 3 IN NEXT CABINET
TO NEXT POS.
NOTE—THESE WIRES ARE ALWAYS PUT IN BY K.S.B.& S.CO. BETWEEN ALL POSITIONS OF ANY ONE CABINET BUT WILL HAVE TO BE PUT IN BY TEL. CO. FROM ONE CABINET TO ANOTHER.
16 C.P. LAMPS
POWER GEN.
TO GENERATOR ALSO WHEN 4 PARTY LINE SELECTIVE RINGING IS FURNISHED
NOTE—7 CELLS FULLER BATTERY ARE USED INSTEAD OF 15 CELLS DRY BATTERY WHEN TRANSFER JACKS ARE FURNISHED.
3-CELLS GRAVITY BATTERY
3-CELLS GRAVITY BATTERY
TRANSMITTER BATTERIES
2-DRY CELLS FOR BUZZER
15-CELLS DRY BATTERY OR 7-CELLS FULLER BATTERY

WIRING OF CORD CIRCUIT,

Kellogg Express Switchboard

TELEPHONY.

PART II.

TELEPHONE LINES.

The fundamental principles upon which the telephone works having been grasped, and the development of the complete telephone traced to its culminating point, it now becomes necessary to take up the subject of the nature of the line or circuit over which the talking current is transmitted, from the originating to the receiving end. Before the subject of line construction is taken up, however, it will be necessary to become familiar with the nature of the work required of the line, together with its disposition and arrangement, in order that the proper connections may be made in the quickest and most economical manner.

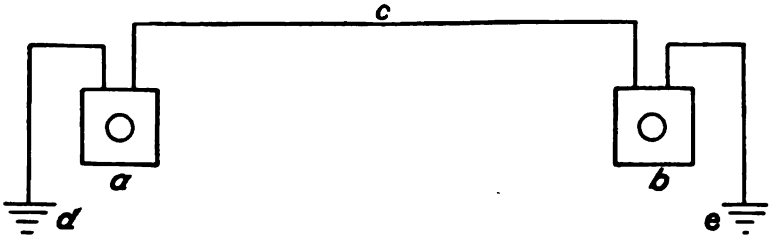


Fig. 60.

Telephone lines must not only be so constructed mechanically and electrically as to carry properly the talking current, but also be so distributed as to afford, at a minimum expense of material and labor, access to all points to which access is desired. The work of arranging lines with the object mentioned above is called **distribution,** and is based upon the following principles:

The simplest method of distribution that can be conceived is that in which two telephones are connected together by a line either grounded or metallic, as shown in Figs. 60 and 61. In Fig. 60, *a* and *b* represent two telephones connected by the line *c*, the return circuit being made through the ground between the points *d* and *e*. In Fig. 61, *a* and *b* again represent two telephones; but here they are connected by a metallic circuit *c*. The relative merits of the grounded and the metallic circuits will be discussed later.

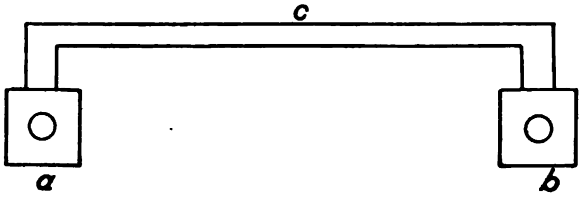


Fig. 61.

With the arrangements shown in Figs. 60 and 61, evidently communication can be established only between the two points *a* and *b*, either in one direction or in the other. If it be desired to establish communication with a third point, a third telephone may be bridged upon the line as shown at *d* in Fig. 62. In this case, communication can be established between *a* and *b*, *a* and *d*, or *b* and *d*. If a fourth point is to be brought into communication, this can be done as shown in Fig. 63, where *e* represents the additional telephone bridged on the line at this point. If the new points of communication lie beyond *a* or *b*, the line can be extended accordingly and the additional telephone bridged on as before.

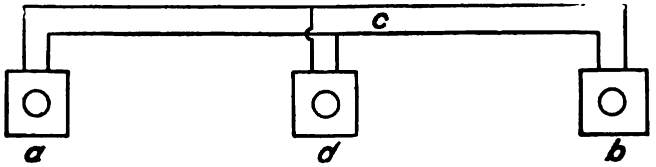


Fig. 62.

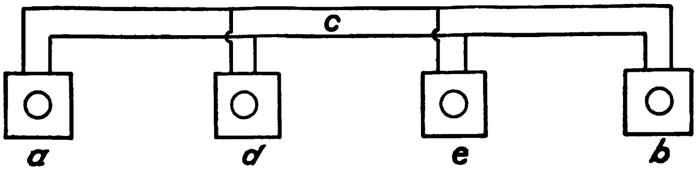


Fig. 63.

It is evident that the flexibility of this system is limited by the greatest number of telephones that can be bridged on a line without cutting down the talking current to such an extent as to render transmission unsatisfactory, or the ringing current to such an extent as to render the amount of signaling current that passes through each bell insufficient to ring it. Besides these two considerations, there is an additional one — namely, the fact that a signal cannot be sent from any one station to any other without it being received at the remaining stations. Nor can conversation be carried on between any two stations without the possibility of it being overheard at the others, or without precluding the possibility of independent conversation being carried on between any of the others. It will be obvious that if each of the telephones be connected to a separate line, and if these lines be run to a common point at which is placed suitable apparatus for their connection together in any desired order, the above-mentioned difficulties will be overcome. In Fig. 64 is shown such an arrangement, where the four telephones *a*, *b*, *c*, and *d* are connected respectively to the lines 1, 2, 3, and 4, which lines run to the common point *e*. By means of suitable apparatus placed at *e*, the circuit 1 can be connected to circuit 2, 3, or 4, and communication thus established for *a* with either *b*, *c*, or *d* as desired. Similar connections can be made for *b*, *c*, and *d*.

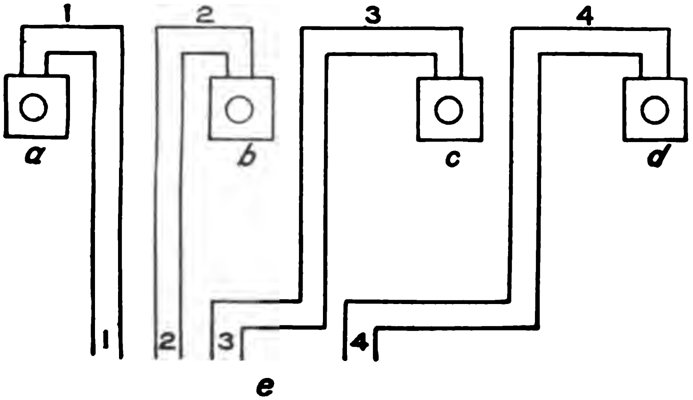


Fig. 64

So far as the problems of transmission are concerned, the number of telephones that can be connected to the common point *e* is unlimited ; nor would the problems of line construction have any bearing on the subject. The point to which these lines are run is called an **exchange** or **central office.** An employee must be placed in the exchange to make the connections required; and in order to attract the attention of this person, each line is equipped with a signal so designed as to be operated automatically by the generator at the telephone.

The lines above described are called **subscriber** or **sub-station lines** from the fact that they connect the subscriber telephones to the exchange. By some telephone engineers the subscriber telephones are called **sub-stations,** whence the additional title.

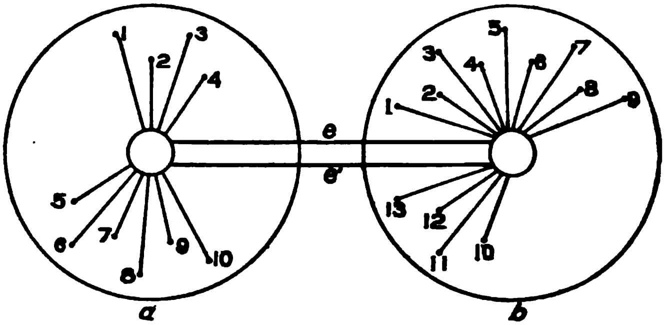


Fig. 65.

There are limitations to the number of subscriber telephones that can advantageously be connected to one and the same exchange, and among these limitations one of the most important is the cost of the line construction. To illustrate this point, in Fig. 65 let *a* and *b* be two towns situated in proximity to each other, and suppose that telephone communication is first established in the town *a*. After a while the inhabitants in town *b* desire to have communication. If only three or four people in the latter town desire service, it will probably be most economical to connect them by direct lines to the exchange in *a*. As the number of subscribers increases, however, a time will arrive when it will be most advantageous to establish an exchange in *b* and connect to it all the subscriber telephones in this town. Then, to afford means of establishing communication between the two towns, a number of lines will be built between the two exchanges.

The point at which it becomes most economical to open a new exchange in the town *b* will depend on the following factors:

Assuming the quality of line construction to be standard, the number of telephones that could be most economically operated through the exchange at *a* would vary inversely as the distance between the two towns. It would vary directly with the cost of establishing and maintaining an exchange at *b*, which would itself depend on the cost of rent and the operator's salary. It would be influenced also by the number of communications established between the two towns.

In Fig. 65 the numbers 1, 2, 3, etc. represent the subscriber stations in each of the towns, while the two lines *e* and *e'* represent the two circuits joining the exchanges. The lines that so connect the two exchanges are called **trunk lines**. When a toll rate is charged for communicating over these trunk lines, they are called **toll lines**. In large cities, where the cost of line construction is high, it is advantageous to have several exchanges connected by trunk lines as shown in Fig. 65.

It will be obvious that each subscriber line may be connected to as many telephones as it will carry under the limitations of transmission and signaling described above. Such an arrangement would be obtained by extending the line *c*, Fig. 63, to the exchange. In practice this is constantly done. Exclusive of toll lines, trunk lines never terminate in more than two stations, one at each end. Toll lines, on the other hand, are sometimes connected to three or more stations.

In the most advanced practice the location of the business and its probable growth are determined beforehand as accurately as possible, and the distribution of subscriber lines is made from these data. In this way the work of subscriber-line construction can be pushed in advance of daily needs. The largest companies plan subscriber-line requirements for two or three years in advance of actual needs. Under these conditions the subscriber lines are built to predetermined points of distribution. The idea will be better understood

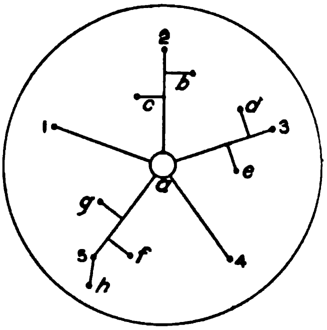


Fig. 66.

by reference to Fig. 66, where *a* represents an exchange situated in a large town or city. Let 1, 2, 3, 4, and 5 represent centers of distribution, that is, points about which the subscriber telephones cluster. To handle this business properly, lines, whose number would depend upon the number of subscribers, would be run out to these points as shown. To provide for cases in which more than one telephone is connected to a circuit, some of the lines are equipped with branches as shown at *b*, *c*, *d*, etc. in the figure. These branches are made in two ways. Either a certain number of wires are turned aside at the branching point, or the required number of wires are bridged off the lines at that point. This is illustrated in Fig. 67, where the figures 1 to 11 represent metallic lines emerging from an exchange. At the point *a* the lines 8 to 11 are turned aside and proceed to the point *b*. This is a *split* branch. At the point *c* the lines 1 to 4 are bridged to lines of the same number and proceed to *d*. This is a *bridging* branch. The lines 1 to 7 proceed to the main point of distribution *e*. The points *b* and *d* are branch points of distribution. Should it be required to connect a subscriber telephone at *d* to the same line as is already connected to a telephone at *e*, this could readily be done by connecting the two telephones to one of the lines

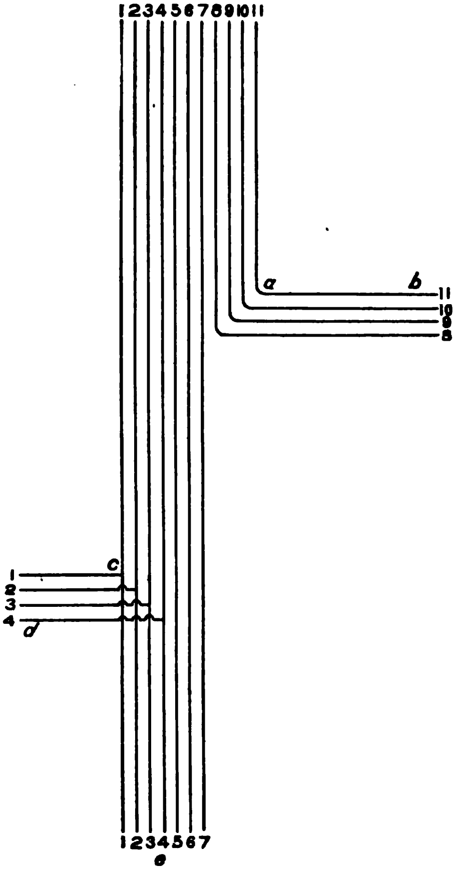


Fig. 67.

1 to 4. Should it be required to connect a subscriber telephone at *b* to the same line as that carrying a telephone at *e* or *d*, the bridge would have to be made at the central office. This is sometimes advantageous. The centers of distribution, whether main or branch, should be so located that the distance from any one of them to the most remote subscriber telephone is not over 300 feet. In most cases this can be accomplished. This condition enables a subscriber telephone to be connected to the exchange by merely running from it a line to the distribution point. Such a line can be run in from ½-hour to two hours' time, and can be readily removed at small cost should occasion require. This line is called the **bridle** or **drop line.** Looked at from the standpoint of distribution, therefore, telephone lines are divided into two classes: **Subscriber lines** and **Trunk lines.** Each partakes of distinctive features to be described later.

LINE CONSTRUCTION.

The subject of distribution having been understood, it is now time to consider the methods adapted for line construction and to describe fully the nature of the materials required in this work. Looked at from the standpoint of construction, telephone lines may be divided into two classes: **Open-wire lines** and **Cable lines.** Open-wire lines are those in which each wire is run independently of its neighbors, and insulated from them by sufficient air space. The wires are tied to glass insulators which are placed on wooden pins set in holes on a wooden cross-arm. This cross-arm is fastened to a pole set in the ground, and at a sufficient height not to obstruct traffic. Cable lines are those in which the wires, each insulated by a suitable covering, are twisted together in cable form and securely bound. The cable may be covered with a layer of tape saturated with tar, or may be encased in a lead pipe. Both classes have special spheres of usefulness and are of equal importance. The open-wire line is used almost exclusively in country districts, and to a large extent in suburban districts. It is also used in small cities and, in a few instances, in large cities.

The cable line has the advantage of being capable of use for either overhead or underground work. In Fig. 68 is shown the top of a pole equipped with two cross-arms, each accommodating ten pins. The pole is shown at *a*, and the two cross-arms at *b* and *c*.

The cross-arms are fastened to the pole by means of bolts which pass through the pole, being secured by nuts resting on washers as shown at *f* and *f′*. The cross-arm is held rigid by two cross-arm braces, as *e* and *d*, which are secured to the cross-arm by two carriage bolts, as *g* and *g′*, and to the pole by a drive-screw, as *h*. The spacing of the cross-arms is 2 feet and that of the pins 12 inches. Upon these pins are placed glass insulators, as shown at *i* and *j*. The insulators are constructed with a semicircular depression as shown, which is for the reception and securing of the wire.

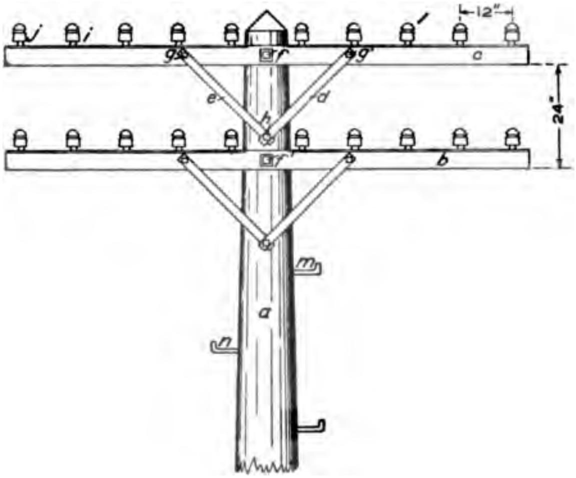


Fig. 68.

For use in climbing the pole, steps are driven on opposite sides, as shown at *m* and *n*. The cross-arm bolts with their washers, the cross-arm braces, the carriage bolts, the drive-screws, the pole steps, the pins, and the insulators are referred to as **pole fittings,** and will be discussed under that heading in this book.

The Pole. This is the most important feature of the open-wire lines, and since it has to bear the load of the wires under all conditions it is essential that the wood used be selected with the utmost care. In America the following woods are used for this purpose:

Norway pine	lasts 6 years.
Chestnut	" 16 years.
Cypress	" 12 years.
White cedar	" 10 years.

In former days white cedar was the favorite wood among telephone engineers on account of its combination of strength and lightness. Chestnut, however, on account of its durability and toughness, is coming to replace cedar; and the Bell companies, in building new lines or rebuilding old ones, use this wood almost exclusively. Juniper is also coming into favor, being used extensively in the South. Although not quite so strong as chestnut, it gives very good results.

Everybody is familiar with the annual rings exhibited by a cross-section of a tree when sawed through. These are caused by the difference in the rate of growth of the tree in spring and in autumn. In spring, when the ground is soft and the leaves fully developed, the rate of growth is quicker than in the fall, when the conditions are the reverse. As a result the wood grown in the earlier season is less dense than that formed under more adverse conditions. The annual rings consist therefore of nothing more than layers of porous spring wood alternating with layers of dense fall wood. Trees planted in barren soil grow less rapidly than those in more fertile soil, and for the reason explained above contain a greater percentage of dense wood. They are what is technically known as "slow growth" timber and are the best suited for telephone poles.

Whatever kind of wood is selected, it should have the following qualities: It should be live and green, reasonably straight, well proportioned from butt to top, and free from loose knots, and should have the hard knots trimmed close. The pole should be squared at both ends. The size of pole required will depend on the number of wires to be carried and on the height of the obstacles, if any, to be overcome. The shortest pole, however, should be of sufficient height to have the lowest wire at least 20 feet above the ground.

The size of the diameter of the pole will depend upon its height, for the higher the pole the greater the load it will have to support and therefore the greater will be the strength required. Attempts have been made to figure out the required shape and size that a pole must have to be of the most economical volume to support the required load. Results, however, have shown that if a pole has the ordinary taper, all that is required is to specify that it shall have a circumference of 22 inches at the top, or be about 7 inches in diameter. The diameter at the butt will then be of the proper dimensions no matter what the height of the pole may be. The following table gives the requisite dimensions of cedar, chestnut, and juniper poles for pole lengths ranging from 30 to 90 feet :

TABLE I.

Pole Dimensions.

CEDAR POLES.

Length.	Circumference at Top.	Circumference 6 feet from Butt not less than
30 feet.	22 inches.	36 inches.
35 "	22 "	38 "
40 "	22 "	43 "
45 "	22 "	47 "
50 "	22 "	50 "

CHESTNUT POLES.

30 feet.	22 inches.	36 inches.
35 "	22 "	40 "
40 "	22 "	43 "
45 "	22 "	47 "
50 "	22 "	50 "
55 "	22 "	53 "
60 "	22 "	56 "
65 "	22 "	59 "
70 "	22 "	62 "
75 "	22 "	65 "
80 "	22 "	69 "
85 "	22 "	72 "
90 "	22 "	75 "

JUNIPER POLES.

30 feet.	22 inches.	37 inches.
35 "	22 "	40 "
40 "	22 "	44 "
45 "	22 "	48 "
50 "	22 "	52 "

The following table gives the weight of cedar and Norway pine poles for lengths between 25 and 85 feet. The diameter at the top for the cedar poles is approximately 7 inches, varying between 5 and 7 inches. For the Norway pine poles the diameter of the pole at the top is 7 inches in every case.

TABLE II.

Pole Weights.

CEDAR POLES.

LENGTH.	DIAMETER AT TOP.	WEIGHT.
25 feet.	5 inches.	200 pounds.
25 “	6 “	275 “
30 “	6 “	325 “
30 “	7 “	450 “
35 “	6 “	500 “
35 “	7 “	600 “
40 “	6 “	700 “
40 “	7 “	800 “
45 “	6 “	950 “
45 “	7 “	1,100 “
50 “	6 “	1,250 “
50 “	7 “	1,450 “
55 “	6 “	1,500 “
55 “	7 “	1,800 “

NORWAY PINE POLES.

40 feet.	7 inches.	1,100 pounds.
45 “	7 “	1,200 “
50 “	7 “	1,350 “
55 “	7 “	1,500 “
60 “	7 “	1,700 “
65 “	7 “	2,000 “
70 “	7 “	2,400 “
75 “	7 “	2,800 “
80 “	7 “	3,400 “
85 “	7 “	3,800 “

In Fig. 69 is shown a standard pole for any required length. The top is cut into a wedge shape with an angle of 90° between the two sides. This is called “framing,” and is done to throw off water. At *a*, *a′*, *a″*, etc., are shown rectangular depressions called **gains.** The center of the first gain is 10 inches below the top of the pole, and the succeeding gains are 24 inches apart. These gains are cut in a vertical line down one side of the pole, with their faces at right angles to the direction of the wires. The frame at the top of the pole has its edge parallel to the direction of the wires. The gains are cut 4¼ or 4½ inches broad and 1½ inches deep. They are for the reception of the cross-arms.

Many attempts have been made with more or less success, to treat poles artificially so as to protect them against the action of the weather. One method is to expel the sap, and fill the pores with creosote, or dead oil of tar. The results have been only measurably successful, as the creosote, though adding to the life of the pole, reduces its strength. The general practice is to paint the pole thoroughly after it has been placed. The frame and the gains are treated to three coats of the best white lead.

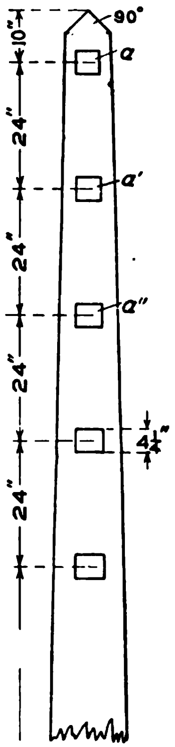


Fig. 69.

The point at which the pole is most liable to decay is at the surface of the ground. This is because at this point the action of the dampness in the ground and in the air is greatest. Various methods have been devised for protecting poles at this point, such as coating with tar and the like, but the general practice today is to depend altogether on paint. Poles should be cut about one year before they are to be used, and should be peeled of bark as soon as possible after they are cut. Square and hexagonal poles are sometimes used, but only in extraordinary cases, such as when passing through a town where the inhabitants are particular about appearances. They are usually creosoted though sometimes painted. Poles occasionally have hollow hearts, by which term is meant the condition where a pole has decayed at its axis. This condition is very hard and sometimes impossible to detect, but on the other hand does not materially weaken the pole until it has progressed very far.

The Cross-Arm. The cross-arm is next in importance to the pole, and the utmost care should be taken in the selection of the material for its construction, and in the proper design. Three kinds of wood are used in the construction of cross-arms: Norway pine, cypress, and yellow pine. The same dimensions are used with all three. Cross-arms made out of Norway pine and cypress are painted, but when yellow pine is used they are usually creosoted.

The process of creosoting is as follows: The timber is subjected to either live or superheated steam for from 3 to 6 hours, depending on the condition of the timber. The temperature of the timber must not exceed 250° Fahrenheit. The steam is then withdrawn, and the timber placed in a vacuum of 26 inches until the water and sap have been removed. The chamber containing the timber is next filled with the dead oil of tar at a temperature of not less than 120° F nor more than 250° F, and pressure is applied until the requisite amount of oil has been forced into the timber.

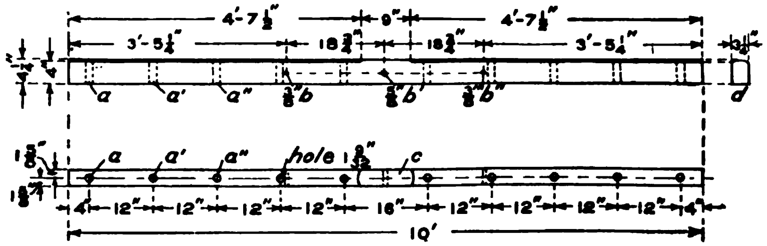


Fig. 70.

Cross-arms are of two sizes. The **Standard cross-arm,** for general use, is shown in Fig. 70. The **Terminal cross-arm,** for use, as its name indicates, at terminal points, is shown in Fig. 71. Whatever the kind of wood used, it should be thoroughly seasoned, straight-grained, and free from injurious shakes or unsound knots. Referring to Fig. 70 the elevation of the cross-arm is shown above, while the plan is shown below. The length over all is 10 feet. The top is arched, as will be seen in the end view at *d*, to throw off water. A space 9 inches long in the center of the arm is flattened as shown at *c*. This is done to prevent the water running into the gain. The pin holes are shown both in plan and in elevation at *a*, *a'*, *a''*, etc. They are $1\frac{9}{32}$ inches in diameter and are spaced 12 inches on centers. The center of the end pin is 4 inches from the end of the arm. The distance between the two pins nearest the

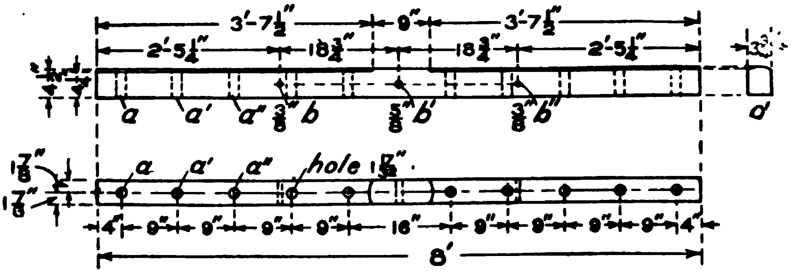
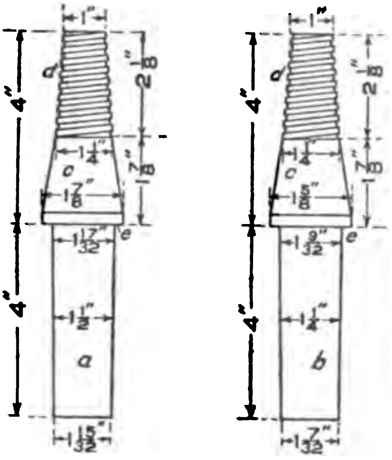


Fig. 71.

pole is 16 inches. Looking at the elevation it will be seen that there are three holes bored through the axis of the arm. One, shown at b', is $\frac{5}{8}$ inch in diameter and is in the center of the arm. The other two, shown at b and b'', are $\frac{3}{8}$ inch in diameter and are spaced $18\frac{3}{4}$ inches on each side of the center hole. The center hole is for the reception of the cross-arm bolt, while the other two are to receive the carriage bolts for fastening the cross-arm braces. The cross-sectional dimensions of the arm are 4 inches high by $3\frac{1}{4}$ inches wide, the height to the top of the arch being $4\frac{1}{4}$ inches.

The terminal cross-arm is shown in Fig. 71, the upper view being the elevation, while the lower one is the plan. It will be seen that the length over all is 8 ft., or two feet shorter than in case of the standard cross-arm. The cross-sectional dimensions are larger than those of the standard arm, being $3\frac{3}{4}$ inches wide by $4\frac{1}{4}$ inches high, with a height of $4\frac{1}{2}$ inches to the top of the arch. The spacing of the pin holes is 9 inches as against 12 inches for the standard arm. Three holes, shown at b, b', b'', are bored through the axis, having the same dimensions and the same location as those already shown in the standard arm. The terminal cross-arm is made heavier than the other, for the reason that it is used on the pole where the line terminates, and has therefore to bear a greater strain than the arms used at other points of the line. In shape and method of construction, the terminal cross-arm is the same as the standard. The pin holes are $1\frac{17}{32}$ inches in diameter, for the accommodation of a larger-sized pin than those used on the standard arm.

Pins. Pins used in telephone work are made almost exclusively of locust. Orangē wood is used somewhat throughout the South and makes a very good pin, but with this exception locust is universally used. Pins are of two classes: **Standard pins** and **Transposition pins.** Both of these classes of pins are made in two sizes, one to fit the holes on a standard cross-arm, and the other to fit those on a terminal cross-arm. In Fig. 72 is shown a standard pin, that marked A being for a terminal cross-arm, while that marked B is for a standard cross-arm, the difference between the two lying solely in the girth dimensions. The upper part of the pin, for a distance of $2\frac{1}{8}$ inches from the top, is threaded for the reception of the glass insulator. Below the threaded portion is a taper-shaped hood *c*, which terminates in an overhang shown at *e*. The part below this is in the form of a conical-shaped shank, with its greatest diameter above and its smallest below. The shank *a* or *b* is introduced into the hole on the cross-arm, and makes a binding fit when the overhang *e* touches the top of the arm. This overhang is designed to throw off water and prevent its running down into the hole. To hold it securely to the arm a tenpenny nail is driven through the side of the cross-arm and the pin.



A B

Fig. 72.

A transposition pin for a standard and a terminal cross-arm is shown in Fig. 73. It will be observed that the main difference between the transposition pins and the standard pins lies in the fact that the threaded portion is longer in the former than in the latter. The standard pin is threaded to a point $2\frac{1}{8}$ inches from the top, while the transposition pin is threaded to a point $3\frac{1}{4}$ inches from the top. The extra amount of threaded surface on the transposition pin is for the accommodation of the transposition insulator, to be shown directly. The diameter of the threaded portion of the pins, whether transposition or standard, and whether used on a standard or on a terminal cross-arm, is only one inch, the object being to obviate the necessity of having two sizes of insulators. The strain on a pin comes on the section just below the overhang or hood, so that there is no necessity

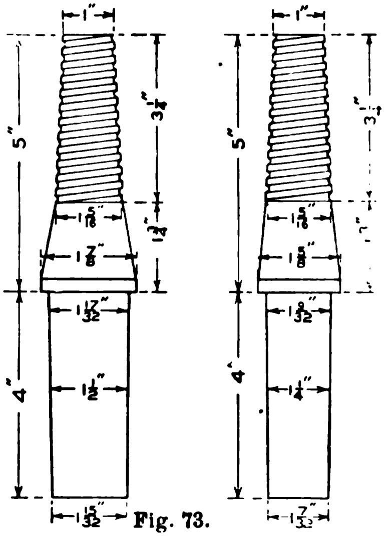


Fig. 73.

of increasing the diameter of the threaded portion on the pins used on a terminal cross-arm.

Insulators. With the exception of that portion of the line known as the drop line or bridle wire, the material used in America in making insulators is glass. In Europe, porcelain is used more extensively. Porcelain has some advantages over glass as a material for making insulators, and on the other hand, glass possesses some advantages over porcelain. Porcelain, when new, has an insulation resistance about 5 or 6 times greater than that of glass. However, in cities or near factories or railroads, the insulators soon become coated with a thin film of dust, so that the insulating powers of the two materials soon become equal. Porcelain is more expensive than glass, and its glazed surface soon becomes cracked under the influence of cold, thus allowing rain to soak into the interior portion and greatly reduce the insulating power. Porcelain is more durable than glass and less likely to succumb to mechanical injury. It is also less hydroscopic; that is to say, it does not so readily condense the moisture in the air into a thin film on its surface. Glass, however, possesses one peculiar advantage over porcelain, which in America it is not well to overlook. Cocoons and spider webs are much less likely to form on glass insulators than on porcelain because glass is transparent and does not offer the shade that seems to be desired by worms and spiders for this work. The fact that glass is cheaper than porcelain and offers quite as good a resistance under every-day working conditions, has caused engineers to adopt it generally for open-wire line construction.

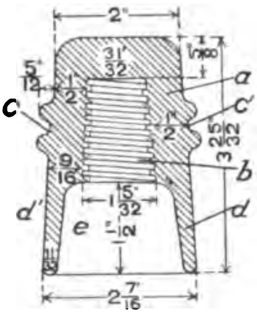


Fig. 74.

Various forms of glass insulators have been put on the market from time to time, each possessing advantages; but after much experience the form shown in Fig. 74 has been found to be the best suited for general use. It is made as light as possible consistent with strength and durability, and is of such a shape as to secure the wire properly and, in addition, offer the greatest insulation resistance. In shape it is like a thick inverted cup, with a heavy bottom *a*. The bottom is bored out and threaded as shown at *b*, to receive the threads on the pin. Around the sides is a semicircular depression *c c'*, which is designed to receive the wire. The side of the cup *d d'*, called the "petticoat," is brought down a good distance to offer as long a path as possible over the surface of the glass to the pin. When screwed on the pin, the hood occupies the greater portion of the space *e*, so that the current, in order to reach the ground, must pass down the outside of the glass, around the edge, and up on the inner side to the pin. Insulation resistance like any other resistance increases with the length of the path traversed. Hence the necessity of bringing the sides of the insulator as far down as possible. The sides of the insulator also form a shield for the pin, and protect it from rain. The principal dimensions are given in the diagram.

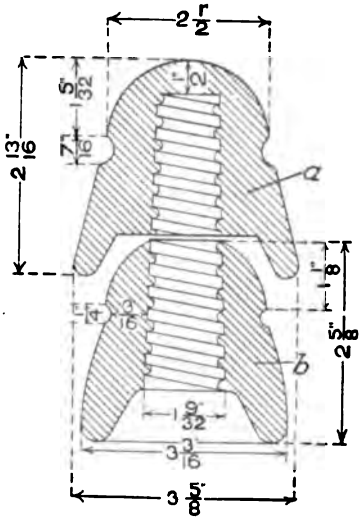


Fig. 75.

In Fig. 75 is shown the most generally adopted form of transposition insulator. It consists in substance of two glasses, one above the other, each one being of the same general design illustrated in Fig. 74. The lower glass *b* is screwed on the pin first, a hole in its top allowing it to descend to the bottom of the thread. The upper one is then screwed into place. The upper one should be so designed that when screwed tight a space of $\frac{1}{32}$ inch will exist between its lower surface and the upper surface of the lower glass. By this means the surface path to ground is broken and the insulation resistance increased. Transposition glasses are sometimes made in one piece, but they fail in so far as they do not possess this feature.

Pole Fittings.—Cross-Arm Bolts. As has already been said, the cross-arm is fastened to the pole by means of a cross-arm bolt. In Fig. 76 is shown a standard cross-arm bolt. It is an iron bolt made of $\frac{5}{8}$-inch stock and cut with a standard thread to a point 5 inches from one end. It is made in five sizes of the following lengths: 10-inch, 13-inch, 14-inch, 15-inch, and 16-inch, to be used according to the size of the pole. The head of the bolt is 1 inch square and $\frac{1}{2}$ inch thick, and the nut is $\frac{5}{8}$ inch thick and 1 inch square. It is thoroughly galvanized, including the thread. In Fig. 77 is shown an iron washer $2\frac{1}{4}$ inches by $2\frac{1}{4}$ inches and of $\frac{3}{16}$-inch stock thoroughly galvanized. Through its center is a hole of $\frac{3}{4}$-inch diameter. Two of these washers are used with each bolt, one to go under the head and the other under the nut.

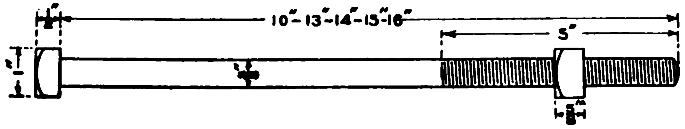


Fig. 76.

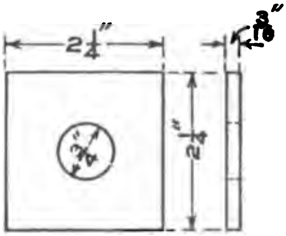


Fig. 77.

Cross-Arm Braces. In Fig. 78 is shown a cross-arm brace. It is made out of iron or low carbon steel thoroughly galvanized, 28 inches long, $1\frac{1}{4}$ inches wide, and $\frac{1}{4}$ inch thick. One inch from each end is a hole, that at one end being $\frac{17}{32}$ inch in diameter for the reception of the fetter drive-screw which holds it to the pole, and the other $\frac{15}{32}$ inch in diameter for the reception of the carriage bolt which secures it to the cross-arm.

Carriage Bolts. In Fig. 79 is shown a carriage bolt. It is made in two sizes, one 4 inches long for use on standard arms, and the other $4\frac{1}{2}$ inches long for use on terminal arms. One end is threaded to a length of $1\frac{1}{4}$ inches for the accommodation of a nut. In connection with this bolt are used two iron washers of the type shown in Fig. 80: they are $1\frac{1}{2}$ inches in diameter and $\frac{1}{8}$ inch thick, with a half-inch hole in the center. Both carriage bolt and washers

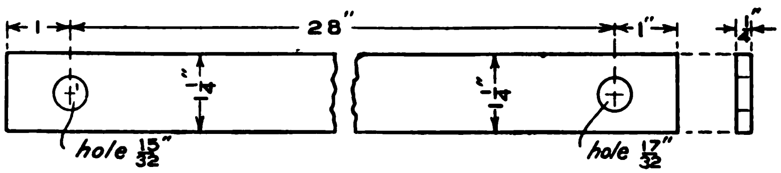


Fig. 78.

are thoroughly galvanized. One washer is placed under the bolthead, and the other under the nut.

Fetter Drive-Screws. In Fig. 81 is shown a fetter drive-screw. It is made of low carbon steel thoroughly galvanized, and threaded to a point about 3 inches from the end. The end is pointed so that it may be driven into the wood with a hammer. These screws are used to fasten the cross-arm braces to the pole.

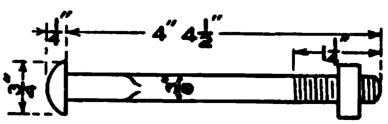


Fig. 79.

Pole Steps. In Fig. 82 is shown a pole step. It is made of thoroughly galvanized iron or low carbon steel 10 inches long and of $\frac{5}{8}$-inch stock. One end is turned up as shown at *a*, to prevent the foot from slipping off as the pole is ascended or descended. The other end is cut with a fetter thread for a distance of about 3 inches, and the end is pointed so that it may be driven into the pole.

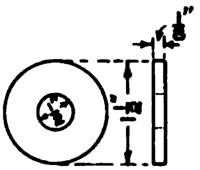


Fig. 80.

Under the head of pole fittings comes a lot of apparatus that will be described now, but whose method of use will be touched on later. In this lot are the following articles: guy rods, thimbles, rock eye-bolts, and guy clamps. These articles are used in strengthening a pole line against excessive strains.

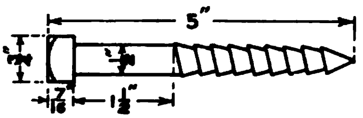


Fig. 81.

Guy Rods. In Fig. 83 will be seen a standard guy rod. It is made of $\frac{5}{8}$-inch iron thoroughly galvanized, and has one end threaded for a distance of 3 inches. The opposite end is bent into the form of an "eye" and welded at *a*. The length over all is 8 feet. In practice this rod is used to secure guy wires to the ground.

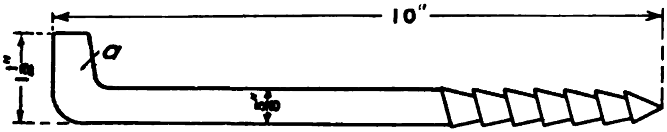


Fig. 82.

Thimbles. A standard thimble is of the shape and dimensions given in Fig. 84. It is made of malleable iron thoroughly galvanized. Its use will be explained later.

Rock Eye-Bolts. In Fig. 85 is shown a standard rock eye-bolt. It is made of a bar of $\frac{5}{8}$ inch wrought iron thoroughly galvanized, and bent double so as to form an eye at *a*. The length when formed is 24 inches. Its use will be explained later.

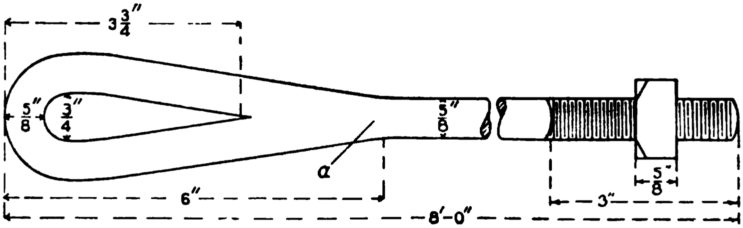


Fig. 83.

Guy Clamps. The standard guy clamp, used in securing guy wire, is shown in Fig. 86. It consists of two pieces of malleable iron thoroughly galvanized, and held together by three bolts. The adjacent surfaces of these two pieces are cut, each with two peculiarly shaped grooves, shown in section at *a b*, *a' b'*, and in plan at *d* and *e*. Each one of these grooves is tapered. The two grooves on one piece taper in opposite directions. When the two pieces are placed together, each groove tapers in the opposite direction to that one

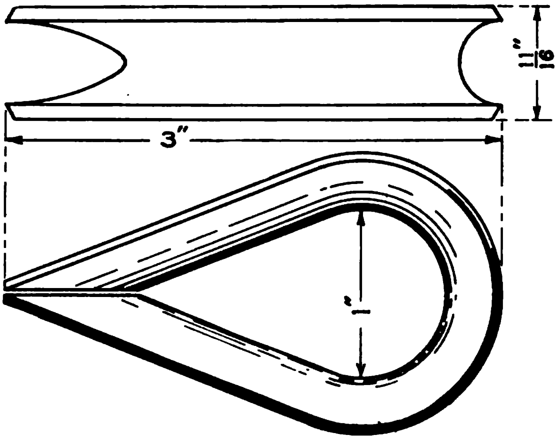


Fig. 84.

directly over it. In this way, when the bolts are tightened, a binding strain is placed upon the guy wire, holding it firmly. The detail of the bolt and nut is shown in Fig. 86*a*. The clamp assembled is shown in Fig. 86*b*.

Laying out the Line. Before constructing a pole line the first work is to determine the most feasible route to be followed. In doing this a great many factors have to be taken into consideration. In general the shortest route should be selected. In doing this, however, the nature of the ground should not be overlooked. Very hard, rocky ground is to be avoided owing to the amount of blasting and hard work it entails in digging the holes. On the other hand very soft earth, such as marsh or swampy ground,

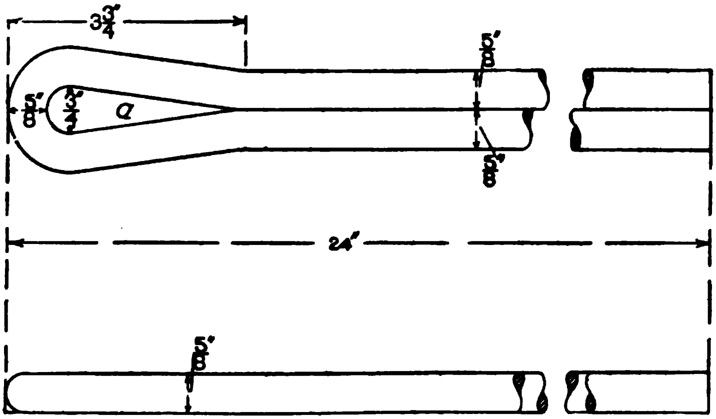


Fig. 85.

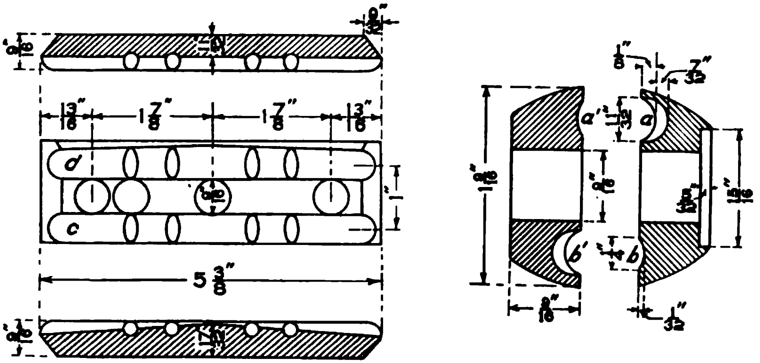


Fig. 86.

should be avoided on account of the cost and delay in building artificial foundations, and also on account of the liability of the poles to settle and fall in spite of the best of foundations. The best soil for a pole line is either sharp sand, or loamy or clayey soil, on account of the ease in digging and the firmness with which it can be packed down when the pole is set.

There is another factor, however, which is far more potent in deciding the course of a pole line, and it is one which does not lend itself to any mathematical solution. That is the **right of way.** Before a pole line can be built on a road or public thoroughfare, the consent of the property owners along the road must be obtained or a franchise from the town or city must be had. In the majority of cases, particularly in small towns and in the country, both must be obtained. The right of way should also include the right to trim any and all trees that may protrude their branches through the line. The route to be selected is the best one according to the above considerations along which a right of way can be obtained.

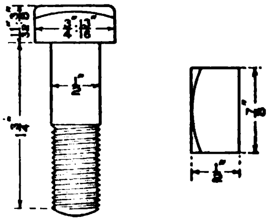


Fig. 86 *a*.

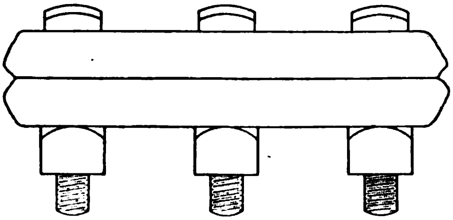


Fig. 86 *b*.

The route having been selected, the next work is to lay off distances of 130 feet and drive a stake in the ground at the end of each distance. Suppose that the problem is to lay out a pole line along the road shown in Fig. 87, in which the road, more or less crooked, is represented as crossing a river *a*. Suppose that the x-marks with their accompanying numbers indicate the position of the stakes. First of all, the curb line must be well defined, or else a series of offsets must be taken from the building line to have the poles properly located, just inside of the curb line. Except in a few isolated cases the curb line is well enough defined for all practical purposes. Supposing this to be the case, the start is made at pole No. 1, presumably just outside of the office. A distance of 130 feet is measured off and at its extremity a second stake is driven for pole No. 2. This process is continued until the river is reached.

In approaching the stream great care should be taken to note the condition of the bank. If the bank be low and marshy the last pole should not be placed very near the water. If, however, the bank is high and firm, the last pole may be placed as near the edge as possible. In approaching the river bank, pole 6 happens to be so located that the space between it and pole 8 is greater than 130 feet. Rather than have an extra long span at this point, an additional pole is placed at x 7, midway between x 6 and x 8. This arrangement helps to support pole 6, which support is probably needed in view of an extra long span across the river. When the river is very wide, say from 250 to 400 feet, and is shallow in addition, a pole is sometimes placed in the center if there is no navigation to be interfered with. Single spans of more than 250 feet across a stream are not permissible, except with special construction to be described later. Where the river is deep enough for navigation, it is best to use a cable of special construction laid on or under the bottom. This point will be dwelt on below.

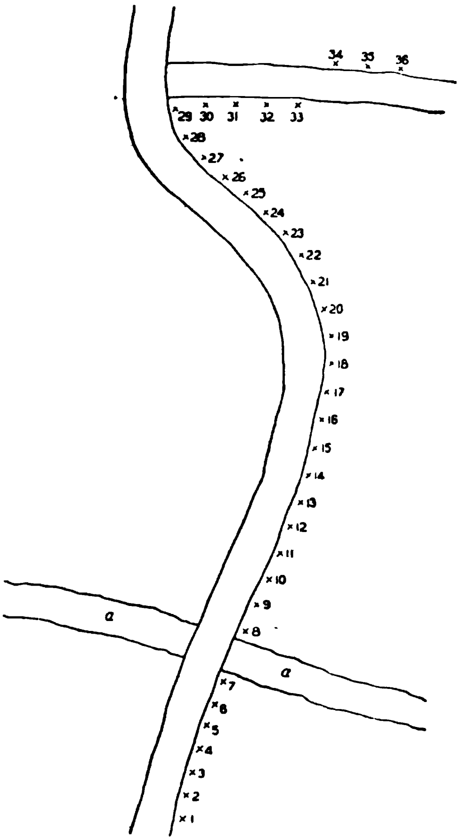


Fig. 87.

In the straight reach between poles 8 and 16 care should be taken to locate the intermediate poles in line. This can be done by having a third man stationed at x 16 to sight back towards x 10 and keep in line the intermediate stakes. Wherever a sharp turn occurs, as at pole 29, the pole should be placed at the point of turning; where the turn is less abrupt, as between x 16 and x 22, this practice is not necessary. Between x 33 and x 34 it will be seen that the line crosses from one side of the road to the other. This is often necessary, where it is impossible to secure a continuous right of way on one side of the road. This crossing over is sometimes done, also, to avoid trees or other obstructions. A crossing should always be made at an angle of 45° with the line of the road.

When the line is built beside a railroad track, the poles should be set at a distance of at least 12 feet from the rail. If there should be a clear space between the top of the rail and the lowest cross-arm of 22 feet or more, the poles may be set at a distance of not less than 7 feet from the rail.

In cities, poles should be set at the corners of intersecting streets so as to admit of guying. At road crossings the lowest cross-arm should be at least 18 feet above the crown of the road. No electric light or power wires should ever be placed above a telephone line, as in case of breakage they would fall across the latter and do serious damage. By placing them beneath the telephone lines this danger is avoided, and the only way in which the telephone lines can become entangled with the high-tension circuit is by themselves breaking. No power or trolley wire should ever be nearer than 6 feet to the nearest telephone wire.

Before going into the method of setting poles, a word should be said upon the subject of placing cross-arms and guying. On straight runs, cross-arms are placed on alternate sides of the pole as shown in Fig. 88. Starting with pole No. 1, the cross-arm is placed on the side of the pole opposite to the direction of the line. At pole 2, the cross-arm is placed on the opposite side. At pole 3 the position is again reversed, so that the cross-arm on this pole and on pole 2 are placed on adjacent sides. This process is continued for straight runs. On long curves the cross-arms are placed on the side of the pole facing the middle point of the curve as shown at 6, 7, 8, 9 and 10, the middle point lying between poles 7 and 8. At pole 10 a straight run begins again, and the cross-arm is placed on the side opposite the direction of the run. At crossings, as between poles 11 and 12, the cross-arms are placed on the sides facing the crossing. The point to be aimed at in placing a cross-arm is to have the pole interposed between the cross-arm and the point from which the strain comes. On a straight run the pull comes from both ends, so that the cross-arms must be placed on alternate sides. As soon as the line begins to curve, however, the curved portion, from the fact that it changes its direction at every point, ceases to be effective in pulling against the straight section, so that the strain at the curve is toward the straight section. As a result the cross-arm must be placed on the side of the pole facing the middle point of the curve.

In addition to supporting the weight of the wires, the pole must also withstand the horizontal strains, and when these become excessive it must be reinforced or strengthened. This reinforcing is called **guying**. The principle of guying will be touched on here. If a curve is situated at the end of a straight run, as between poles 5 and 10, the tendency of the strain on the wires is to pull the poles on the curve towards the center of the curve. A very simple experiment will prove this fact. Set up three or four pins on the arc of a circle. Rigidly fasten one end of a string and draw it around the pins, bringing the end out straight. Grasp the end and pull. The string tends to assume a straight path between the point where it is rigidly held and the hand, and in so doing it will drag the pins over towards the center of the arc. To overcome this effect the poles on a curve, as 6, 7, 8, 9 and 10 in Fig. 88, are fastened by means of stout wire rope to anchor logs

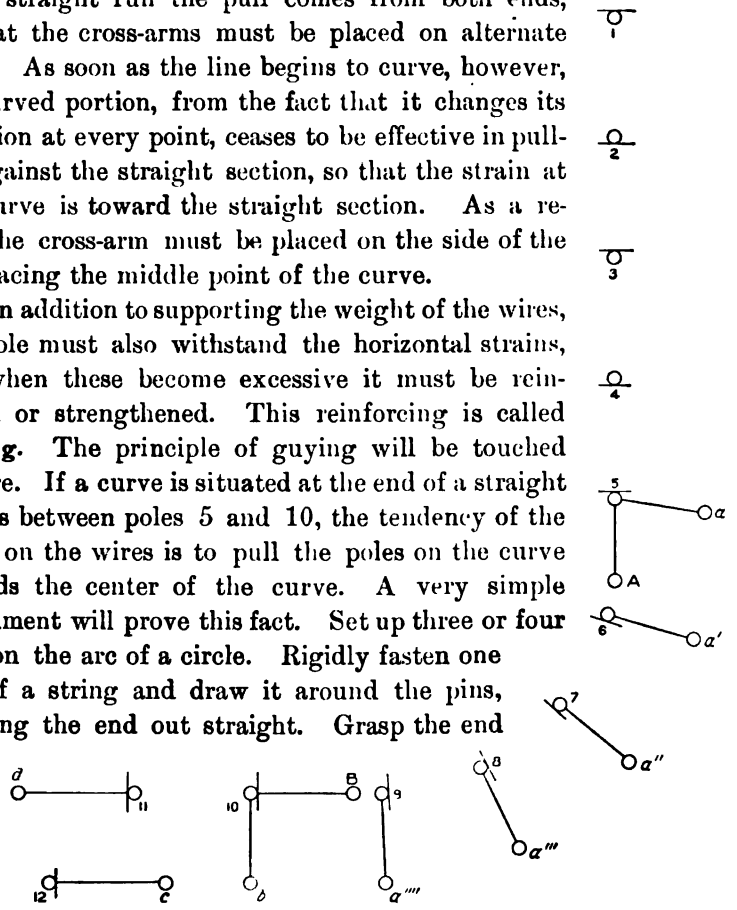


Fig. 88.

shown at a', a'', a''', a'''' and *b*. These anchor logs are short poles planted firmly in the ground. Pole 5 at the end of the straight run is guyed to the anchor log A to prevent its being pulled in the direction of the line. Pole 10 being at the beginning of a straight run is guyed to the anchor log B, and, being the last pole on the curve, is also guyed to the anchor log *b*. At the crossing pole 12 is guyed to *c*, and pole 11 to *d*. A **head guy** is one placed so as to resist the pull towards pole 1. A **back guy** is one so placed as to resist a pull in the opposite direction, as at the beginning of long spans. Thus in Fig. 87 pole 7 and possibly pole 8 would be back-guyed to resist the pull of the span across the river. A **side guy** is one so placed as to resist a pull in a direction at right angles to the direction of the line. Thus in Fig. 88 the guys on poles 6, 7, 8 and 9 are side guys.

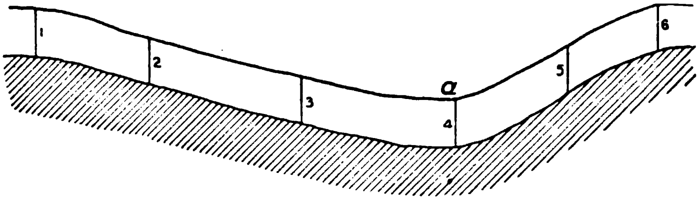


Fig. 89.

In passing through hilly country care should be taken to keep the tops of the poles as nearly level as possible, which is accomplished by placing the longest poles in the lowest places, and the shortest ones in the highest places. An exaggerated example of this condition is shown in Fig. 89, where the figures 1, 2, 3, 4, etc., indicate poles placed in hilly ground. The tension on the wires at the lowest pole *a* tends to lift them up in the air and might under severe conditions pull the wires loose from their fastenings. This effect is overcome by the arrangement shown in Fig. 90, in which the poles increase in length as the hill is descended, the wires themselves being run in a very nearly horizontal direction. Under these conditions the poles should be so spaced that the lowest point of the hollow comes in the middle of a span.

In building a pole line through a very hilly country a profile map of the country should be made or should be obtained from the township authorities. A map that will suit the purpose can be made by the use of a little superficial knowledge of land surveying. All that is necessary in the way of apparatus is a surveyor's theodolite and a leveling pole. They are used in the following way: The theodolite is set up midway between stake No. 1 and stake No. 2, and an assistant stations himself at the former with the leveling pole. The leveling pole is sighted and the point of intersection marked. The pole is then set up at stake 2 and again sighted through the theodolite, the point of intersection being again marked. The distance on the pole between these two points gives the difference in level between stake 1 and stake 2. This process should be repeated for all stakes lying within this territory. The poles to be set are then graded in length to meet the requirements. It is not necessary, and it would be impossible in some localities, to maintain the tops of the poles at a constant level; but sudden and very marked changes in level should be avoided.

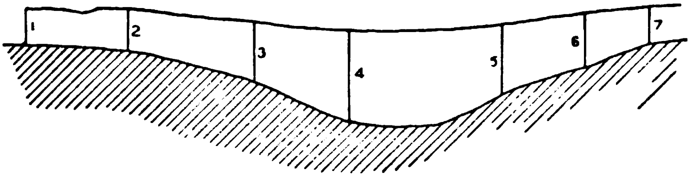


Fig. 90.

Setting and Equipping Poles. The line having been laid out and the stakes driven, the next piece of work is to dig the holes. The method of so doing depends upon the nature of the ground. Where the ground is rocky, blasting must be resorted to. If the line has been properly laid out, however, this should very seldom be the case. Blasting is usually done with a hand drill and a small charge of dynamite. The tools used in digging are shown in Figs. 91, 92, and 93. In Fig. 93 is shown a combined crow and digging bar, one end of which, *b*, is sharpened for digging up the earth, and the other end, *a*, is broadened out for tamping down the earth as it is being filled in around the pole. In digging, the earth is first loosened up with the sharp end of the bar, and when this has been done sufficiently it is excavated by means of the sharp-pointed shovel shown in Fig. 92. As the hole becomes deeper the spoon-shaped shovel shown in Fig. 91 is brought into play, as this is specially designed for lifting the earth out of the hole. In diameter the hole should exceed that of the pole by about 4 or 5 inches, and the depth should vary with the height of the pole to be placed. The following table is a safe one to follow :

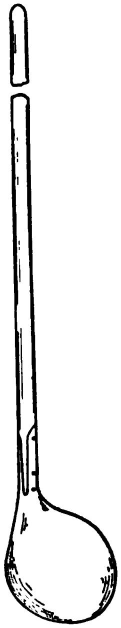


Fig. 91.

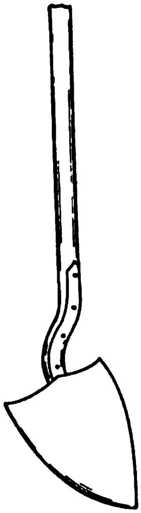


Fig. 92.

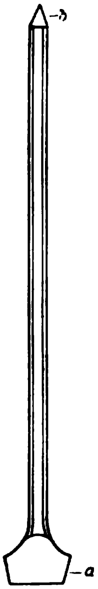


Fig. 93.

TABLE III.
Pole Setting.

Length of Pole.	Depth in Ground.
25 feet.	5 feet.
30 "	5½ "
35 "	6 "
40 "	6 "
45 "	6½ "
50 "	7 "
55 "	7½ "
60 "	8 "
65 "	8½ "
70 "	9 "
75 "	9½ "
80 "	10 "
85 "	10½ "
90 "	11 "

The hole should be of the same diameter at the bottom as it is at the top. Where the ground is very soft it is necessary to construct an artificial foundation for the pole to rest in. This is done in one of three ways which are equally good, and which are illustrated in Figs. 94, 95, and 96. In the method shown in Fig. 94 the hole is dug with a diameter of 3 feet. The butt of the pole is equipped with a platform made of two pieces of planking 33 inches long, 18 inches broad, and 2 inches thick, placed at right angles, and nailed to the bottom of the pole. The arrangement is shown at *a* in the figure. The bottom of the hole is covered to a depth of 12 inches with a mixture consisting of 1 part cement, 2 parts sand, and 5 parts stone. When the pole is set, the platform rests on this foundation, and rubble consisting of the above mixture is filled in around it to within 6 inches of the top of the hole. Earth is then shoveled in and packed down hard.

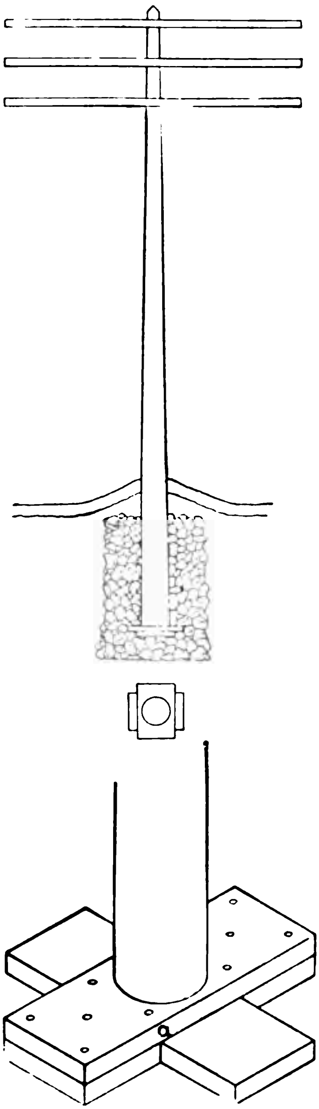


Fig. 94.

The second method, shown in Fig. 95, consists in fastening to the pole at a point 2 inches above the surface of the ground, two yellow pine planks 10 feet long, 8 inches wide, and 2 inches thick. They are placed parallel, and fastened to the pole by means of a cross-arm bolt. From the ends of these two planks four others are brought up to the pole in the manner shown. They are fastened above and below by cross-arm bolts. To the bottom of the horizontal planks are nailed 8 others, 4 on each side of the pole, 3 feet long, 10 inches broad, and 2 inches thick, making a platform for the pole to rest upon. By this arrangement the pole is also braced against lateral strains. The foundation shown in Fig. 94 is best adapted to sandy soil, while that shown in Fig. 95 is more suited to muddy or marshy ground.

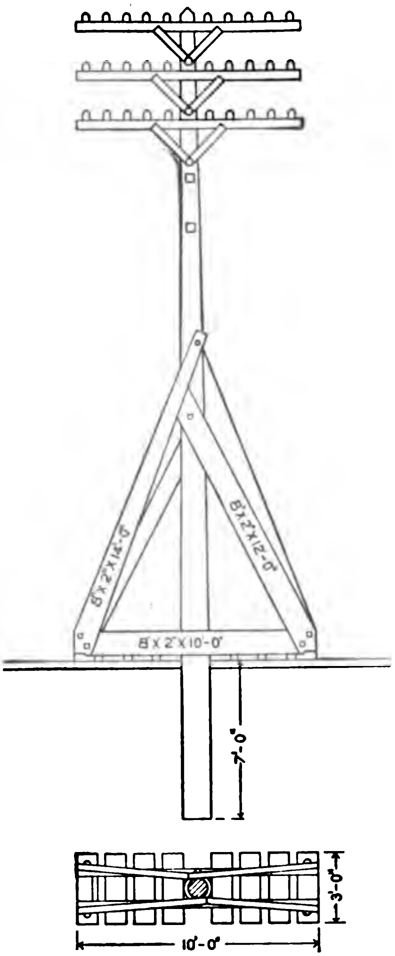


Fig. 95.

A more elaborate development of the framework scheme is shown in Fig. 96, in which two chestnut poles 10 inches in diameter at the top are sunk into the earth, one on each side of the main pole, with their centers about 5 feet 2 inches from its center. Two 8-inch by 2-inch planks, shown at *a*, are fastened to the tops of the two auxiliary poles, being also fastened to the main pole. The upright braces also are fastened to the auxiliary poles. As in the previous figure, planks 3 feet long, 8 inches wide, and 2 inches thick are nailed to the bottom to make a platform. The braces are fastened to the main and auxiliary poles by means of cross-arm bolts. At *b* is shown the method of cutting out the tops of the auxiliary poles to receive the braces.

The holes having been dug, the next step is to erect the poles. These should be distributed along the right of way, the butts being placed at the holes. Where possible, the poles should lie with the top at a greater elevation than the butt, for assistance in raising. When poles of different lengths are used, they should be properly distributed along the right of way. Before the pole is raised it should be moved so as to have the butt resting on the edge of

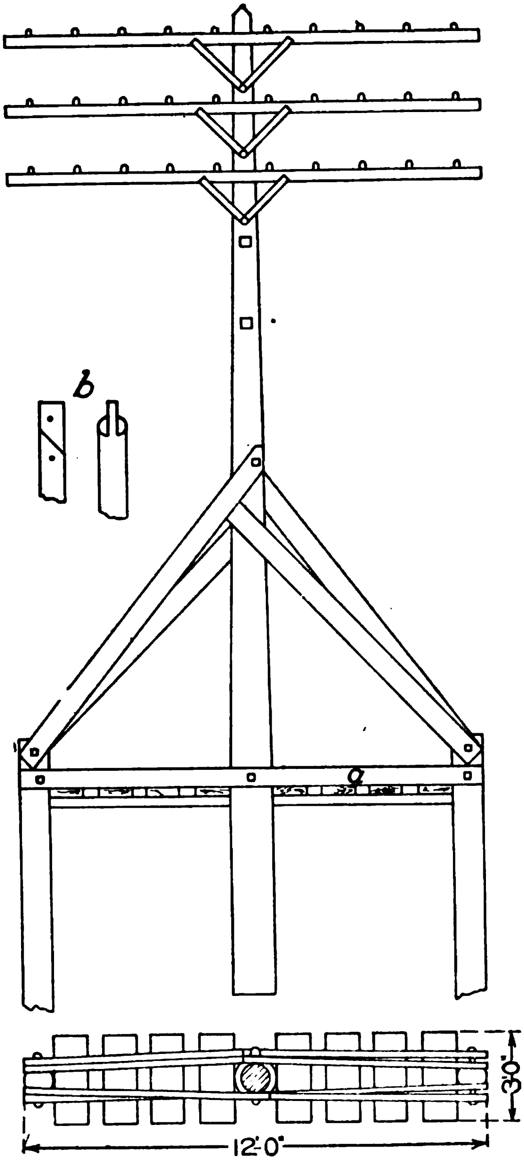


Fig. 96.

the hole. For handling the poles properly a cant hook, shown in Fig. 97, is used. It consists of a heavy ash handle *a*, to which is fastened a wrought-iron spur *b*, pivoted at *c*. In using this tool the pole is caught between the side of the handle, *e*, and the spur, after which, by moving the handle upward, the pole is rolled over. The tongs shown in Fig. 98 are of wrought iron fastened to a heavy ash handle.

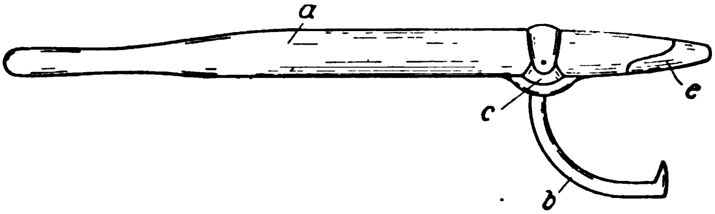


Fig. 97.

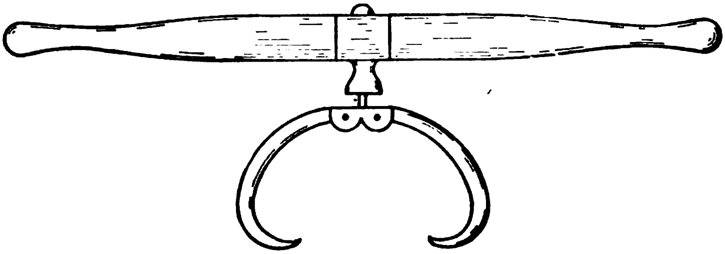


Fig. 98.

When the pole has been properly placed, it is seized at the top by the gang of linemen, usually from 5 to 8 men, and raised. One man shown at *a*, Fig. 99, stands at the hole, and seizing the pole in his arms directs the motion of the butt into the hole. The tools used in pole raising are: a **pike**, shown in Fig. 100, and a **dead man**, shown in Fig. 101. Pikes are made in lengths of from 8 to 14 feet, and consist of an ash pole *a*, Fig. 100, about 2 inches in diameter, surrounded at one end by a wrought-iron ring *b*. Into one end is driven a steel spike *c*. The dead man is made of a heavy ash pole *a*, Fig. 101, with a U-shaped wrought-iron prong *b* at one end, equipped with a spur in the center, shown at *c*. This implement is used to hold the pole in position from time to time as it is being raised. This is being held by the man at *b* in Fig. 99. As soon as the top of the pole is raised high enough to permit of it, four linemen thrust into it the steel spurs of their pikes and are thus enabled to raise it higher still. As the pole is raised nearer and nearer to the perpendicular, the longer pikes come into play, until, when the pole has been elevated to an angle of about 50°, the butt slides into the hole. The pikes are then used to adjust it to a perfectly vertical position. This having been done, the earth is gradually filled in around the pole, being tamped down in the meanwhile by two men using the end *a* (Fig. 93) of their tamping bars. Great care should be taken to pack the earth firmly as it is being put in, and to this end only one shovel is allowed to be used during the process. When the hole has been filled, the surplus earth is piled up around the pole in the form of a mound.

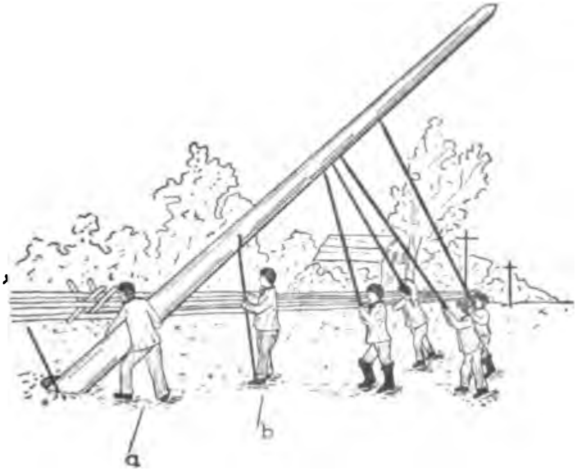


Fig. 99.

In regard to the rate at which poles can be set by the average gang of linemen, it may be said that this is governed by the number of holes that can be dug. Under ordinary conditions about 8 or 10 holes are all that one man can dig in one day. Where blasting has to be resorted to, the rate is much lower. It rarely goes above this. Eight or ten poles set is a good day's work for the average gang.

The poles having been set, the next step is to set the cross-arms. For this purpose a lineman is sent up the pole, with a block which he fastens at the top. A stout Manila rope is then rove through the block, and the cross-arm, being fastened to one end of it, is hoisted to the top of the pole by the men on the ground. The top cross-arm is always set first, the one just beneath it next, and so on. The reason for this arrangement is that poles are not always equipped at once with their full capacity of cross-arms, and frequently, after a line has been put into working order, additional cross-arms have to be placed. If the first cross-arms were placed in the bottom gains, not only would the additional ones have to be carried over the working wires, but the new wires, while being strung, would be sure to hang down and to cause trouble on those already in place. All this is avoided by beginning at the top.

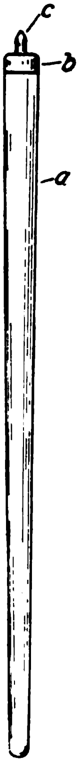


Fig. 100.

The cross-arm having been hauled up within reach of the lineman, it is then seized, the rope is removed, and the arm is placed in position in the top gain, being secured by a cross-arm bolt driven first through the pole and then through the cross-arm. The two cross-arm braces are then fastened to the cross-arm by means of two carriage bolts, which pass first through the cross-arm and then through the brace. The opposite ends of the braces are then brought together and fastened to the pole by means of a fetter drive-screw. If more than one arm is to be placed, the succeeding ones are hoisted into position and secured in the manner already described. On terminal poles, on corner poles, and at the beginning and end of long spans, back braces are used on the cross-arms. The method of their attachment is shown in Fig. 102, where the back braces are shown at *a* and *a'*. They are fastened to the side of both cross-arm and pole opposite that to which the regular brace is fastened. When this work is finished, the poles are ready for the reception of the wire. But before a description of the method of stringing wires is given, it will be necessary to say something about the nature of the material used for wire.

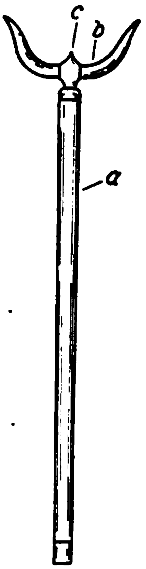


Fig. 101.

TELEPHONE WIRES.

Three kinds of material have been used in the manufacture of wire for telephone use — namely, iron, steel, and copper. In the early days, learning their lesson from the telegraph men, telephone engineers built their lines of iron wire, and it proved practicable for the short distances then in vogue. Steel wire was next selected on account of its greater tensile strength. With the advent of metallic circuits, however, it was found that if the telephone was to be successful for transmission over long distances, some better conductor than iron must be selected. Before discussing at any great length the most suitable metal to use in line construction, it will be necessary for us to understand thoroughly the conducting properties of the various metals used in the mechanic arts.

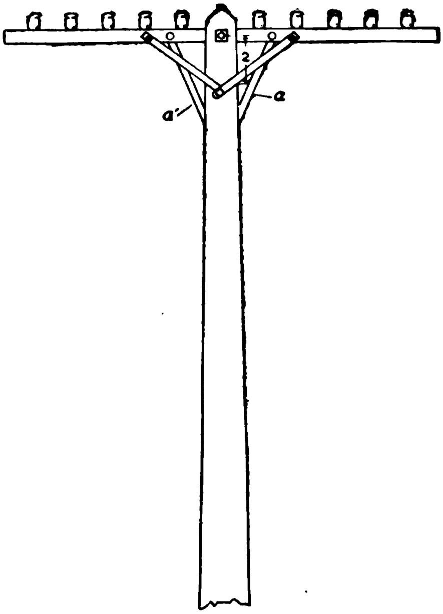


Fig. 102.

The measure adopted for determining the relative merits of different substances as conductors of electricity, is called **Specific Resistance,** which is the resistance between the two opposite faces of a centimeter cube of the substance at a temperature of 0° Centigrade. Table IV gives the resistances of various metallic substances in microhms, or millionths of an ohm.

The **Specific Conductivity** of a substance is the reciprocal of its specific resistance. Substances are compared as to their conducting qualities by what is called **percentage of conductivity.** This is the ratio of the specific conductivity of the substance to that of some standard substance. As a usual thing pure copper is chosen as the standard substance, and the percentage of its conductivity is taken to be 100. The percentage of conductivity of a wire is the ratio that its conductivity bears to that of a pure

TABLE IV.

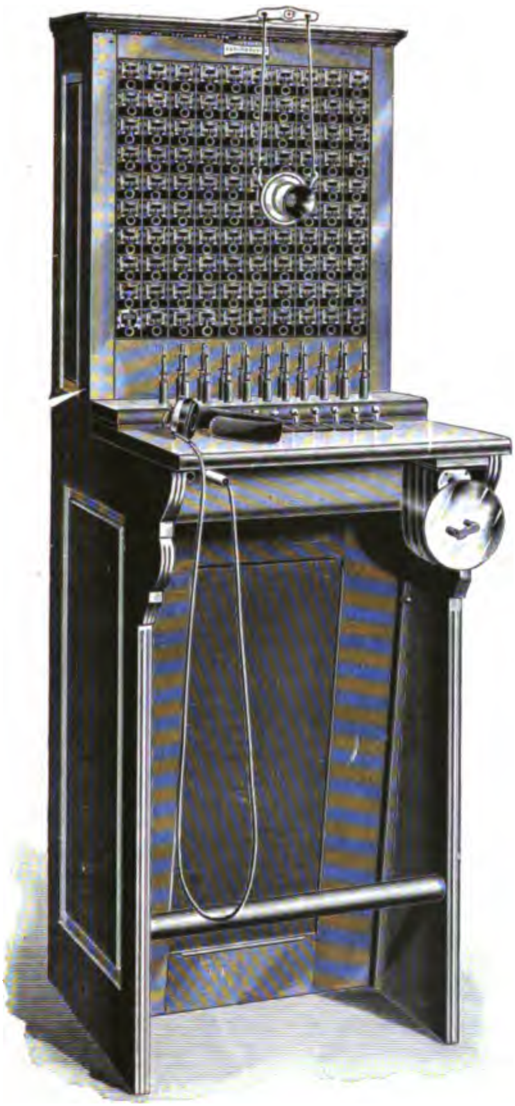
Relative Specific Resistances of Metals.

METAL.	RESISTANCE.	METAL.	RESISTANCE.
Silver, annealed	1.504	Iron, annealed	9.716
Copper, "	1.598	Nickel, "	12.470
Silver, hard-drawn	1.634	Tin, pressed	13.210
Copper, " "	1.634	Lead, "	19.630
Gold, annealed	2.058	German silver	20.930
Gold, hard-drawn	2.094	Antimony, pressed	35.500
Aluminum, annealed	2.912	Mercury	94.320
Zinc, pressed	5.626	Bismuth, pressed	131.200
Platinum, annealed	9.057		

copper wire at the same temperature having the same area of cross-section and the same length. In telephone practice it is usually specified that a conductor shall have a conductivity equal to 98 per cent of that of pure copper. The measure used for determining the diameter of a wire is called the **mil**, and its magnitude is $\frac{1}{1000}$ inch. The unit of cross-sectional area of a conductor is the **circular mil**, which means the area of cross-section of a wire whose diameter is one mil. This forms a more convenient measure than the square inch, since the area bears a very simple relation to the diameter. The area of a circle in square measure is equal to

$$\pi r^2 = \frac{\pi d^2}{4}$$

in which r is the radius of the circle, and d its diameter. If d be expressed in inches, the area $\frac{\pi d^2}{4}$ will be in square inches. If d be expressed in mils, the area $\frac{\pi d^2}{4}$ will be in square mils. Since d is equal to 1, then 1 circular mil is equal to $\frac{\pi}{4}$ mil, and 1 square mil is equal to $\frac{4}{\pi}$ circular mils. Therefore the area of a circle in circular mils will be equal to the area of that circle in square mils multiplied by the number of circular mils in one



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square mil. Thus, if a circle have a diameter d mils, its area in circular mils will be

$$A = \frac{\pi d^2}{4} \times \frac{4}{\pi} = d^2,$$

which means that the area of a circle expressed in circular mils equals the square of the diameter in mils. While the circular mil is the measure of the cross-sectional area of a wire, and forms the basis for figuring out the safe current-carrying capacity, wire is in practice bought and sold according to arbitrary gauges adopted by various manufacturers.

In America the Brown & Sharpe gauge is used almost universally, and was originated by the manufacturers of that name in Providence, R. I. In this system the gauge number diminishes as the diameter of the wire increases. The rule according to which the change is made is a very simple one. If any gauge number be taken as a basis of comparison, then by adding 3 to the gauge number there is obtained the number of a wire whose area is about one-half that of the original. For example, one No. 3 wire will have the same cross-sectional area as two No. 6 wires; and one No. 5 wire will have the same area as two No. 8 or four No. 11 wires. Again, by subtracting 3 from any gauge number, a wire is obtained whose area is about twice that of the original; thus a No. 1 wire has about twice the area of a No. 4.

The following course of reasoning deduced from the abovementioned facts, will enable the student to determine the factor by which the area of a wire of any gauge number must be multiplied or divided in order to obtain the area of the next larger or smaller wire. If the areas of any two consecutive sizes of wire were in the ratio of 2 or 2½, the factors which would be used to determine the area of a wire three sizes larger or smaller would be 2 or ½ because the given area would have to be multiplied either by 2 three times or by ½ three times. In other words, the factor to be used in determining the area of the next consecutive size to the given one, would be the cube root of that used to determine the area of a wire three sizes removed. Now, since this latter factor has been shown to be 2, it follows that the factor necessary to determine the area of the next consecutive size is

$$\sqrt[3]{2} \text{ or } \sqrt[3]{\frac{1}{2}}, \text{ which equals } 1.26 \text{ or } \frac{1}{1.26}.$$

For example, if the area of a No. 6 Brown & Sharpe gauge wire were 26,250 circular mils, the area of a No. 5 wire would be $26{,}250 \times 1.26 = 33{,}075$ circular mils; and in like manner the area of a No. 7 wire would be $26{,}250 \times \frac{1}{1.26} = 20{,}834$ circular mils.

Again, since the ratio of the resistances of two wires varies inversely as the ratio of their areas, it follows that the same two factors can be used to determine the ratio of the resistances of any two wires whose gauge number is known, if the resistance of one of them is given. Thus, if the resistance of a foot length of No. 10 B. & S. gauge copper wire be .001 ohm, the resistance of a No. 11 B. & S. gauge copper wire will be $.001 \times 1.26 = .00126$ ohm. The other wire gauges are the Washburn & Moen Manufacturing Co.'s gauge, the G. W. Prentiss gauge, the British Standard gauge (abbreviated, S. W. G.), the Birmingham or Stubs wire gauge (abbreviated B. W. G.), the Trenton Iron Company's gauge, and the Old English gauge. A table of these gauges will be given directly.

Copper as a Conductor. Reference to the table of relative specific resistances given above will show that silver is the only metal whose specific resistance is less than that of copper. Silver, however, on account of its cost, is excluded from the metals suited for telephone purposes. In looking farther down the list it will be seen that iron is the only other metal that from a commercial standpoint is suited for the manufacture. But the specific resistance of iron as compared with copper is as 6 to 1, which means that of two wires of the same length, one iron and the other copper, the former would have to possess 6 times the area of the latter to have the same conductivity. As a result, if iron wire were used in telephone line construction, it would have to be of such large diameter to compete successfully with copper in point of transmission, as to render the problems of line construction very much more difficult than they now are, and to add very materially to the cost of building.

Copper, when exposed to the air, forms on its surface an oxide which is not soluble in water and which therefore presents a protecting shield against further corrosion of the metal. The oxide of iron, on the other hand, is readily soluble in water, and therefore fresh surfaces of the iron are always presented to the atmosphere. For this reason iron exposed to the weather is soon rusted away. The requisite size of an iron wire, moreover, would preclude its use in cables. Copper has therefore come to supplant iron in line construction, and is now universally used by the leading companies. Pure annealed copper has a specific gravity of 8.89 at 60°F. One cubic inch weighs 0.32 lb. and the melting point of the metal is about 2,100°F. Annealed copper does not possess sufficient tensile strength to make it practicable for wire. The process of hard-drawing it, however, has overcome this difficulty, and copper wire used in line construction is manufactured in this way. Dr. Matthiessen made a determination showing that a piece of soft copper wire, one foot long and having a diameter of 1 mil, has a resistance of 9.612 legal ohms at a temperature of 0° Centigrade. Tables V and VI, which are based on Matthiessen's standard, give the resistances and weights of all sizes of wire according to the B. & S. and the B. W. G. gauges respectively.

In line construction the following sizes of wire are used:

For trunk and subscriber lines not over 50 miles in length — No. 12 N. B. S. G. hard-drawn copper.

For long-distance lines, 500 to 1,000 miles or over — No. 8 B. W. G. hard-drawn copper.

For subscriber lines not over 3 or 4 miles in length — No. 14 B. & S. hard-drawn copper.

NOTE. The above wires are all bare of insulation.

For bridle or drop wires — No. 12 B. & S. hard-drawn copper, insulated.

Other sizes are sometimes used for special cases. This point, however, will be taken up later.

Iron wire, although largely superseded by copper, is still used in country districts, where little long-distance business is done, and where the subscribers have not yet been educated up to the point where they are familiar with and demand the best transmission.

As iron rapidly corrodes, or "rusts," when exposed to the air, the iron wire used in line construction is **galvanized**, which means, covered with a film of zinc. This is accomplished in the following manner: The iron wire, while hot, is drawn through a vat of hydrochloric acid to render the surface perfectly clean. It is immediately afterwards drawn through a vat of molten zinc, which

TABLE V.

Weights and Resistances of Wires, B. & S. Gauge.

Gauge No. B. & S.	Diameter, Mils.	Area, Circular Mils.	Area, Square Inches.	Weights—Specific Gravity, 8.89.				Resistance at 68° F, in International Ohms, Based upon Matthiessen's Standard.				
				Pounds per 1,000 ft.	Pounds per Mile.	Feet per Pound.	Ohms per Pound Annealed.	Ohms per 1,000 Feet.		Ohms per Mile.		Feet per Ohm Annealed
	d	d²						Pure Annealed.	Hard-Drawn.	Pure Annealed.	Hard-Drawn.	
0000	460.000	211600.00	.1661900000	640.50000	3381.400	1.561	.00007639	.04893	.050086	.25835	.26419	20440.000
000	409.640	167805.00	.1317900000	508.00000	2682.200	1.969	.00012150	.06170	.063094	.32577	.33314	16210.000
00	364.800	133079.40	.1045200000	402.80000	2126.800	2.482	.00019310	.07780	.079558	.41079	.42007	12850.000
0	324.865	105534.50	.0828870000	319.50000	1686.900	3.130	.00030710	.09811	.100380	.51802	.52973	10190.000
1	289.300	83694.20	.0657320000	253.30000	1337.200	3.947	.00048830	.12370	.126490	.65314	.66790	8083.000
2	257.630	66373.00	.0521280000	200.90000	1060.600	4.977	.00077650	.15600	.159530	.82368	.84239	6410.000
3	229.420	52634.00	.0413390000	159.30000	841.090	6.276	.00123500	.19670	.201140	1.03860	1.06210	5084.000
4	204.310	41742.00	.0327840000	126.40000	667.390	7.914	.00196300	.24800	.253610	1.30940	1.33920	4031.000
5	181.940	33102.00	.0259990000	100.20000	529.060	9.980	.00312200	.31280	.319870	1.65160	1.68890	3197.000
6	162.020	26250.50	.0206180000	79.46000	419.550	12.580	.00496300	.39440	.403320	2.08250	2.12950	2535.000
7	144.280	20816.00	.0163510000	63.02000	332.750	15.870	.00789200	.49730	.508540	2.62580	2.68500	2011.000
8	128.490	16509.00	.0129670000	49.98000	263.890	20.010	.01255000	.62710	.641270	3.31110	3.38590	1595.000
9	114.430	13094.00	.0102830000	39.63000	209.240	25.230	.01995000	.79080	.808760	4.17530	4.27690	1265.000
10	101.890	10381.00	.0081548000	31.43000	165.950	31.820	.03173000	.99720	1.019900	5.26570	5.38480	1003.000
11	90.742	8234.00	.0064656000	24.93000	131.630	40.120	.05045000	1.25700	1.285400	6.63690	6.78690	795.300
12	80.808	6529.90	.0051287000	19.77000	104.390	50.590	.08022000	1.58600	1.621800	8.37410	8.56330	630.700
13	71.961	5178.40	.0040672000	15.68000	82.791	63.790	.12760000	1.99900	2.044300	10.55500	10.79400	500.100
14	64.084	4106.80	.0032254000	12.43000	76.191	80.440	.20280000	2.52100	2.577900	13.31100	13.61200	396.600
15	57.068	3256.70	.0025579000	9.85800	52.050	101.400	.32250000	3.17900	3.250800	16.78500	17.16500	314.500
16	50.820	2582.90	.0020285000	7.81800	41.277	127.900	.51280000	4.00900	4.099600	21.16800	21.64600	249.400
17	45.257	2048.20	.0016087000	6.20000	32.736	161.300	.81530000	5.05500	5.169200	26.69100	27.29400	197.800
18	40.303	1624.30	.0012757000	4.91700	25.960	203.400	1.29600000	6.37400	6.518800	33.65500	34.41600	156.900
19	35.890	1288.10	.0010117000	3.89900	20.595	256.500	2.06100000	8.03800	8.219600	42.44100	43.40000	124.400
20	31.961	1021.50	.0008023100	3.09200	16.324	323.400	3.27800000	10.14000	10.372000	53.53900	54.74900	98.660
21	28.462	810.10	.0006362600	2.45200	12.964	407.800	5.21200000	12.78000		67.47900		78.240
22	25.347	642.40	.0005045700	1.94500	10.268	514.200	8.28700000	16.12000		85.11400		62.050
23	22.571	509.45	.0004001500	1.54200	8.142	648.400	13.18000000	20.32000		107.29000		49.210
24	20.100	404.01	.0003173300	1.22300	6.457	817.600	20.95000000	25.63000		135.53000		39.020
25	17.900	320.40	.0002516600	.96990	5.121	1031.000	33.32000000	32.31000		170.59000		30.950
26	15.940	254.10	.0001995800	.76920	4.061	1300.000	52.97000000	40.75000		215.16000		24.540
27	14.195	201.50	.0001582700	.61000	3.221	1639.000	84.23000000	51.38000		271.29000		19.460
28	12.641	159.79	.0001255100	.48370	2.554	2067.000	133.90000000	64.79000		242.09000		15.430
29	11.257	126.72	.0000995360	.38360	2.025	2607.000	213.00000000	81.70000		431.37000		12.240
30	10.025	100.50	.0000789360	.30420	1.606	3287.000	338.60000000	103.00000		543.84000		9.707
31	8.928	79.70	.0000625990	.24130	1.274	4145.000	538.40000000	129.90000		685.87000		7.698
32	7.950	63.21	.0000496430	.19130	1.010	5227.000	856.20000000	163.80000		864.87000		6.105
33	7.080	50.13	.0000393680	.15170	.810	6591.000	1361.00000000	206.60000		1090.80000		4.841
34	6.305	39.75	.0000312210	.12030	.635	8311.000	2165.00000000	260.50000		1375.50000		3.839
35	5.615	31.52	.0000247590	.09543	.504	10480.000	3441.00000000	328.40000		1734.00000		3.045
36	5.000	25.00	.0000196350	.07568	.400	13210.000	5473.00000000	414.20000		2187.00000		2.414
37	4.453	19.83	.0000155740	.06001	.317	16660.000	8702.00000000	522.20000		2757.30000		1.915
38	3.965	15.72	.0000123450	.04759	.251	21010.000	1387.00000000	658.50000		3476.80000		1.519
39	3.531	12.47	.0000097923	.03774	.199	26500.000	2200.00000000	830.40000		4384.50000		1.204
40	3.145	9.89	.0000077634	.02993	.158	33410.000	3498.00000000	1047.00000		5528.20000		.955

TABLE VI.

Weights and Resistances of Wires, B. W. G.

Gauge No. B. W. G.	Diameter in Mils, d.	Area in Circular Mils. (C. M. = d^2.)	Weights.		Resistances in International Ohms, Based upon Matthiessen's Standard at 68° F.	
			Pounds per 1,000 Feet.	Pounds per Mile.	Ohms per 1,000 Feet.	Ohms per Pound.
0000	454	206116	624.000	3294.000	.05023	.00008051
000	425	180625	547.000	2887.000	.05732	.00010480
00	380	144400	437.000	2308.000	.07170	.00016400
0	340	115600	350.000	1847.000	.08957	.00025600
1	300	90000	272.000	1438.000	.11500	.00042230
2	284	80656	244.000	1289 000	.12840	.00052580
3	259	67081	203.000	1072.000	.15430	.00076010
4	238	56644	171 000	905.000	.18280	.00106600
5	220	48400	146 000	773.000	.21390	.00146000
6	203	41209	125.000	659.000	.25130	.00201400
7	180	32400	98.000	518.000	.31960	.00325800
8	165	27225	82.000	435.000	.38030	.00461500
9	148	21904	66.000	350.000	.47270	.00712900
10	134	17956	54.000	287.000	.57660	.01061000
11	120	14400	44.000	230.000	.71900	.01650000
12	109	11881	36 000	190.000	.87150	.02423000
13	95	9025	27.300	144.000	1.14700	.04199000
14	83	6889	20 800	110 000	1.50300	.07207000
15	72	5184	15.700	83.000	1.99700	.12730000
16	65	4225	12.800	68.000	2 45100	.19160000
17	58	3364	10.200	54.000	3.07800	.30230000
18	49	2401	7.300	38.400	4 31200	.59330000
19	42	1764	5.300	28.200	5.87000	1.09900000
20	35	1225	3.700	19.600	8.45200	2.27900000
21	32	1024	3.100	16.400	10.11000	3.26200000
22	28	784	2 400	12.500	13.21000	5.56500000
23	25	625	1.900	10.000	16.57000	8.75600000
24	22	484	1.500	7.700	21.39000	14.60000000
25	20	400	1.200	6.400	25.88000	21.38000000
26	18	324	.980	5.200	31.96000	32.58000000
27	16	256	.770	4.100	40.45000	52.19000000
28	14	196	.590	3.100	52.83000	89.04000000
29	13	169	.510	2.700	61.27000	119.80000000
30	12	144	.440	2.300	71.90000	165.00000000
31	10	100	.300	1.600	103.50000	342.00000000
32	9	81	.250	1.300	127.80000	521.30000000
33	8	64	.190	1.020	161.80000	835.10000000
34	7	49	.150	.780	211.30000	1425.00000000
35	5	25	.076	.400	414.20000	5473.00000000
36	4	16	.048	.256	647.10000	13360.00000000

is kept at a uniform temperature of 740° F. When the wire thus coated is exposed to the atmosphere, an oxide of zinc is formed on the surface. This oxide, however, not being soluble in water, remains on the wire and protects it from further corrosion.

When galvanized iron is exposed to the action of sulphur or chlorine, which occur in the exhausts of locomotives, in factory chimneys, etc., zinc sulphate or zinc chloride is formed. Both of these salts are soluble in water, so that the zinc coating is soon eaten away, leaving the surface of the iron exposed. For this reason iron wires that cross railroad tracks are soon eaten away, and usually do not last more than six months or a year.

TABLE VII.

Properties of Galvanized Iron and Steel Wires, B. W. G.

Number, B.W.G.	Diameter in Mils = d.	Area in Circular Mils = d².	Weight in Pounds.		Breaking Strengths in Pounds.		Resistance per Mile (International Ohms) at 68° F.		
			1,000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3 42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5 97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	6.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8 21	9.60	11.35
7	180	32,400	85 0	450	1,350	2,545	10 44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14 53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31 0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	120	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57 44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120 40	139.00
18	49	2,401	6.3	33	99	189	140.80	164.80	194.80

The three grades of iron wire used are designated by the terms Extra Best Best, Best Best, and Best. These grades differ in point of internal structure, and also in conductivity. Table VII gives the properties of Extra Best Best, Best Best, and Steel wire according to the Birmingham Wire Gauge.

Table VIII shows the tensile strength of various sizes of copper wire.

TABLE VIII.

Tensile Strength of Copper Wire.

Number, B. & S. Gauge.	Breaking Weight in Pounds.		Number, B. & S. Gauge.	Breaking Weight in Pounds.	
	Hard-Drawn.	Annealed.		Hard-Drawn.	Annealed.
0000	8310	5650	9	617	349
000	6580	4480	10	489	277
00	5226	3553	11	388	219
0	4558	2818	12	307	174
1	3746	2234	13	244	138
2	3127	1772	14	193	109
3	2480	1405	15	153	87
4	1967	1114	16	133	69
5	1559	883	17	97	55
6	1237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

Table IX gives the factors by which the resistance of a copper conductor at an observed temperature must be multiplied to determine its resistance at 75° F. Thus, if the resistance is 12.746 ohms at 88° F, the resistance at 75° F will be 12.746 × .9728, or 12.399 ohms.

TABLE IX.

Factors for Calculating Resistance of Copper Wire at 75° F.

Temperature, in Degrees F.	Factor	Temperature, in Degrees F.	Factor.	Temperature, in Degrees F.	Factor.	Temperature, in Degrees F.	Factor.
100	.9484	82	.9853	64	1.0236	46	1 0634
99	.9504	81	.9874	63	1.0258	45	1.0657
98	.9524	80	.9895	62	1.0280	44	1.0679
97	.9544	79	.9916	61	1 0301	43	1.0702
96	.9564	78	.9937	60	1.0323	42	1.0725
95	.9585	77	.9958	59	1.0345	41	1.0748
94	.9605	76	.9979	58	1.0367	40	1.0771
93	.9626	75	1.0000	57	1.0389	39	1.0793
92	.9646	74	1.0021	56	1.0411	38	1 0816
91	.9666	73	1.0042	55	1.0433	37	1.0839
90	.9687	72	1.0064	54	1.0455	36	1.0862
89	.9708	71	1.0085	53	1.0478	35	1.0885
88	.9728	70	1 0106	52	1.0500	34	1.0908
87	.9749	69	1 0128	51	1.0522	33	1.0932
86	.9769	68	1.0149	50	1.0544	32	1.0954
85	.9790	67	1.0160	49	1.0567		
84	.9811	66	1.0193	48	1.0589		
83	.9832	65	1.0214	47	1.0612		

In recent years, with the great lowering in the cost of production of aluminum, attempts have been made to use this metal in many of the mechanic arts. Among the suggestions made is one for its use in the manufacture of telephone wire. The great advantage of this metal lies in its comparative lightness.

Table X gives the relative qualities of aluminum and copper.

TABLE X.

Properties of Aluminum and Copper.

	ALUMINUM.	COPPER.
Conductivity (for equal sizes)	.54 to .63	1
Weight (for equal sizes)	.33	1
Weight (for equal length and resistance)	.48	1
Price—Al. 29c., Cop. 16c. (bare line-wire)	1.81	1
Price—(Equal resistance and length bare line-wire)	.868	1
Temperature coefficient per degree F.	.002138	.002155
Resistance of mil-foot (20°C)	18.73	10.5
Specific gravity	2.5 to 2.68	8.89 to 8.93
Breaking strength (equal sizes)	1	1

Table XI gives the properties of the different grades of aluminum wire manufactured by the Pittsburg Reduction Company.

To sum up, the only advantage to be gained by the use of aluminum would lie in the fact that it is lighter than copper. To offset this, however, the diameter of the wire would have to be larger than that of a copper wire for the same conductivity, thus offering a greater resistance to the wind. The greater surface of the aluminum wire would cause a greater electrostatic capacity to exist between it and the ground than would be the case with copper wire. There would, moreover, be a greater difficulty in soldering aluminum joints than copper joints. In view of these facts, it does not seem possible that aluminum will ever supplant copper in line construction.

Tie Wires. The line wires are tied to the insulators by means of short pieces of wire called **tie wires.** The wire used for this purpose should always be of annealed copper of the same gauge as the wire to be tied. It should be cut into lengths of about 18 inches.

Stringing Wires. The poles having been erected and the cross-arms fitted, the next piece of work to be done is to string the

TABLE XI.

Resistance, Tensile Strength, and Weight of Aluminum Telephone Wire.

No., B. & S. Gauge.	Diameter in Mils. d.	Area in Circular Mils. d^2.	Area in Square Inches $\frac{d^2 \times .7854}{1,000,000}$	Grade A o.		Grade A 75.		Grade A 2.		Pounds per Mile. Sp.Gr.2.68. Water, 62.355 lbs. perCub.Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given. Grade A 75.
				Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.	Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.	Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.		
4	204.31	417,420	.0327840	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	331,020	.0259980	.5058	27.500	.5488	34,000	.5818	42,000	159.30	266.4
6	162.02	262,505	.0206170	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	208,160	.0163490	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	165,090	.0129660	1.6340	30,000	1.1050	37,000	1.1870	48,000	79.46	133.2
9	114.43	130,940	.0102840	1.2780	32,000	1.3670	39,000	1.4680	50,000	62.99	105.4
10	101.89	103,810	.0081532	1.6130	33,000	1.7240	40,000	1.8520	51,000	48.71	83.6
11	90.74	82,340	.0064670	2.0330	35,000	2.1730	41,000	2.3350	53,000	39.63	66.3
12	80.81	65,299	.0051286	2.5650	39,000	2.7410	42,000	3.0840	55,000	31.43	52.6
13	71.96	51,784	.0040671	3.2330	....	3.4560	....	3.7120	....	24.88	....
14	64.08	41,068	.0031469	4.1790	....	4.4670	....	4.7980	....	19.76	....
Conductivity. (Pure Copper = 100.)				62.		58.		54.			
Comparative Section of Equal Conductivity. (Copper = 100.)				156.4		167.		180.			
Comparative Weight of Same Lengths of Equal Conductivity. (Copper = 100)				47.		50.2		54.			

wires. When only one or two wires are to be strung at a time, the best method to pursue is to start from the first pole and unwind the wire along the ground at the feet of the poles until the last one has been reached. The wire is then made fast to the proper pins at the first pole, and is carried up over the cross-arm at each succeeding pole. It is then tied to the proper pins.

When several wires are strung at once, as is usually the case, a different method is pursued. As many coils of wire are provided as there are lines to be run, and each coil is placed on what is called a **paying-out reel,** Fig. 103. This consists of a horizontal wheel *a* on the spokes of which are placed four upright arms *b*, *c*, *d* and *e*, which are bent over at the top to prevent the coil of wire being pulled over their ends. The wheel is mounted on a pivot *f*, the bearing of which *g* rests upon a four-legged truck *h*. The coil of wire to be payed out is placed on the wheel, with the four uprights projecting through the center of the coil. The end of the wire is then seized, and, the wheel *a* revolving freely, the coil is easily unwound.

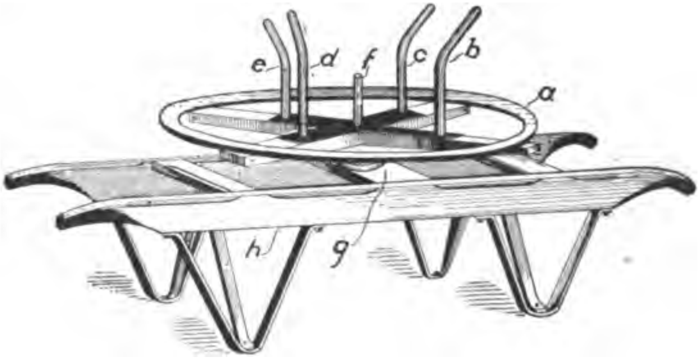


Fig. 103.

The reel, or reels are placed in a convenient location near the foot of the first pole. A piece of apparatus called a **running board** is then provided. This consists of a heavy board, usually of oak, of about the same length as the cross-arm, and having holes bored through it, with the same spacing as that of the pins upon the cross-arm. The ends of the wires are attached at these holes. A stout rope, to be pulled by a horse, is run over the cross-arm, one end of the rope being fastened to the center of the running board.

The horse is then started, and the running board is dragged up to the cross-arm on the first pole, over which it is lifted by a man stationed there. It then passes on to the next pole, carrying the wires after it, and is lifted over the cross-arm as before. As the work progresses the rope is lifted over succeeding cross-arms so as to keep the running board and the wires above them.

When all the wires on the reel have been played out, the ends are fastened to their respective pins at the first pole, and the distant ends of the wire are then grasped and pulled tight. Care must be taken not to pull the wires too tight, as this would result in stretching and thereby materially weakening them. The best way to measure the right amount of tension to exert on the wires is to note the amount of sag in the spans between the poles. The amount of allowable sag depends upon the length of the span, and the temperature of the air. It increases with the length of the span, and decreases with the temperature.

Table XII is one largely used by telephone men in line construction work.

TABLE XII.

Allowable Sag in Wires.

TEMPERATURE FAHRENHEIT.	SPAN 75 FT. SAG.	SPAN 100 FT. SAG.	SPAN 115 FT. SAG.	SPAN 130 FT. SAG.	SPAN 150 FT. SAG.	SPAN 200 FT. SAG.
— 30°	1 inch	2 inch	2½ inch	3½ inch	4½ inch	8 inch
— 10°	1½ "	2½ "	3 "	4 "	5 "	9 "
+ 10°	1½ "	3 "	3½ "	4½ "	6 "	10½ "
+ 30°	2 "	3 "	4 "	5½ "	7 "	12 "
+ 60°	2½ "	4½ "	5½ "	7 "	9 "	15½ "
+ 80°	3 "	5½ "	7 "	8½ "	11½ "	19 "
+100°	4½ "	7 "	9 "	11 "	14 "	22½ "

To illustrate the use of Table XII, take the case of the 75-ft. span. If the wire be strung when the temperature is — 30° F, it may be pulled up until the sag is 1 inch, whereas, if the same wire be strung when the temperature is 100°, a sag of $4\frac{1}{2}$ inches will have to be allowed.

The next piece of work is to tie the wire to the insulators. This is done in two ways, the first of which has passed out of use with the most up-to-date companies. It is illustrated in Fig. 104, where *a* represents the top of the insulator, *d d* the line wire, and *b* the tie wire as it lies in the groove in the insulator. The ends of the tie wire are wound around the line wire as shown at *c c*, four and a-half turns being taken. This method of tying was the one used altogether in connection with iron wire.

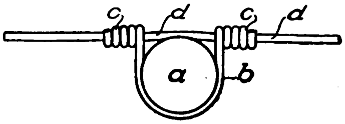


Fig. 104.

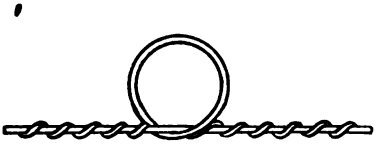
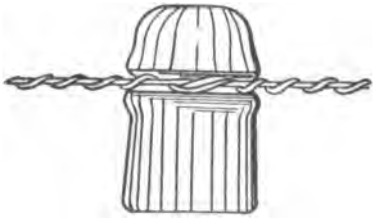


Fig. 105.

With the advent of copper wire, however, a different method of tying was found necessary; and the one illustrated in Figs. 105, 105 A and 105 B, has come to be adopted. Looking at the last figure, 105 B, it will be seen that the tie wire is passed around the glass in one complete turn, one end being passed under, and the other over the line wire. The ends are then wrapped around the line wire in 5 complete turns, which are not laid as close together as those of the old tie but are more spread out. The completed tie is shown in Fig. 105 A, and the plan of it is seen in Fig. 105.

There are two methods of making joints in the wires. One of these, now passing out of use, is shown in Fig. 106, and is called the **Western Union splice.** It is made by wrapping the ends of the two wires about each other in the same manner as in the old form of tying. This joint should always be soldered, and in so doing the heat should be applied at the center point, as the solder takes hold best under these conditions. This form of joint is being superseded by that made by the **McIntire sleeve,** which



ig. 105 A.

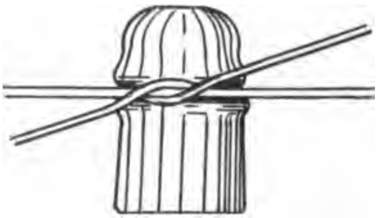


Fig. 105 B.

is shown in Fig. 107, and which consists of two copper tubes *a* and *b* sweated together. These sleeves are made in various sizes to accommodate the different sizes of wire used. The two wires to be joined are introduced into the holes *c* and *d* respectively. The sleeve is then twisted through three turns as shown in Fig. 108, in which *a* represents one of the wires entering one side of the sleeve, and *b* the end of the same wire emerging from the sleeve. The other wire *c* is brought in from the opposite direction, and its end is shown emerging at *d*. The sleeve is given three turns, as already said, and the short ends *b* and *d* are slightly bent over as a further precaution against their pulling out. This class of joint need not be soldered.

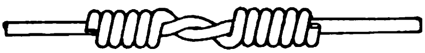


Fig. 106.

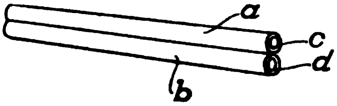


Fig. 107.

The line wires should always pass through the groove in the insulator on the side facing the pole, except in the case of the two insulators nearest the pole, which should have the line wires tied on the side away from the pole. In turning a corner the wires should be tied on the outside of the insulators so that the tension will cause them to press against the glass.

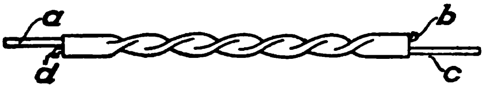


Fig. 108.

In stringing wires the start is made from the central office, and the work is carried on in the direction in which the line is to run. Where the line wire is terminated on a cross-arm, it is said to be **dead-ended**, which is done in the manner shown in Fig. 109. The line wire *d* is passed around the insulator *a* as shown at *b b b* and then through a McIntire sleeve *c*. This sleeve is given one and a-half turns. The end of the wire is shown at *e*.

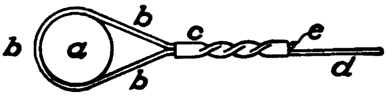


Fig. 109.

Guying. Under this heading is included all the work necessary to make the line secure against extraordinary stresses such as have already been alluded to. The material used in fastening the pole to whatever object has been selected with a view to securing greater rigidity for the line, is called **guy rope** or **guy strand.** The standard guy strand is made of seven steel wires, each of a diameter not more than .111 inch nor less than .107 inch. Each wire must be free from scales, inequalities, and other imperfections, must be of uniform diameter and be drawn in one continuous length, and must be thoroughly galvanized. The wires are twisted together, the length of the twist not to exceed 3½ inches. The strand must have a breaking weight of at least 6,000 pounds, and must elongate not more than 17 per cent nor less than 11 per cent of its length before breaking.

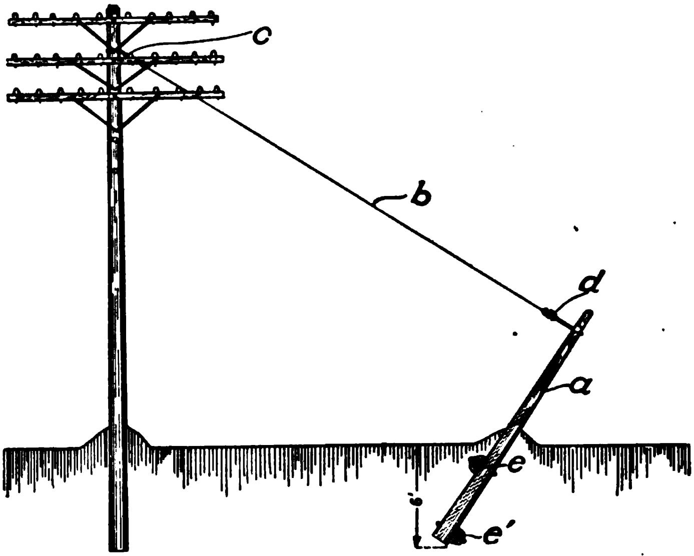


Fig. 110.

One method of fastening the guy strand is shown in Fig. 110. One end of the strand is wrapped twice around the pole at *c*, being held in place by means of staples, and secured by a standard guy clamp. When the pole is equipped with more than one cross-arm, the strand is attached just above the second arm. When the pole is equipped with only one arm, the strand is attached just below the second gain. To secure the other end of the strand, a **guy stub,** shown at *a*, is sunk in the ground in the manner depicted. The strand is wound twice around the stub, being held in place by staples, and is secured by means of a standard **guy clamp**, shown at *d*.

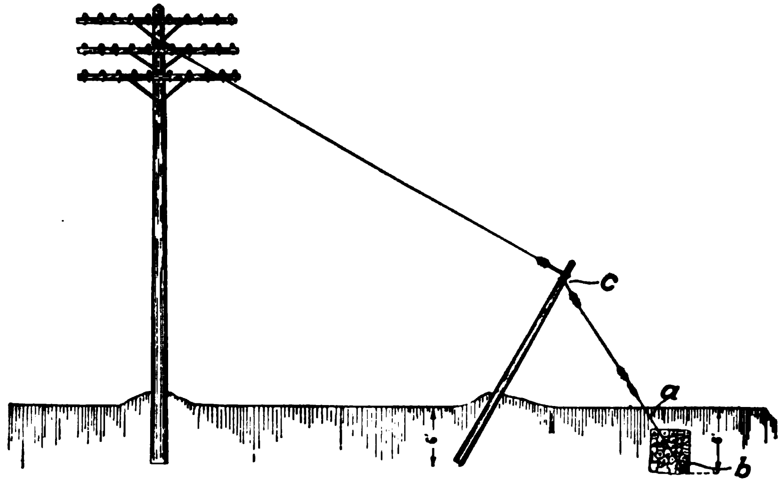


Fig. 111.

There are two ways of setting guy stubs, both of which are equally efficient. The method shown in the figure consists in fastening to the stub two logs of chestnut, shown at *e* and *e'*. These must be 5 feet long and 10 inches in diameter, and fastened to the stub by cross-arm bolts. The upper one *e* is placed on the side facing the pole and at a depth of about one foot. The second one *e'* is placed on the opposite side and at a depth of about 6 feet. These two logs, acting together, prevent the stub from being pulled into a vertical position by the strain on the strand. It should be observed that the earth is piled up around the guy stub in the same manner as around the pole.

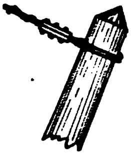


Fig. 112.

When the above method is not used, a separate anchor must be provided for the stub, as shown in Fig. 111. In this case an **anchor-rod**, shown at *a*, is fastened to a chestnut log *b* 5 feet long and 10 inches in diameter, sunk 6 feet in the earth under a pile of **rocks**. The "eye" end of the rod projects about

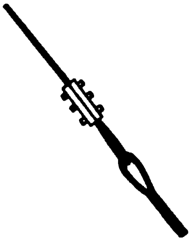


Fig. 113.

one foot above the surface of the ground. One end of a piece of guy strand is wrapped around the guy stub in the usual manner, as shown at *c*, and is secured with a guy clamp. A standard thimble, Fig. 84, is placed through the "eye" in the anchor-rod, and the other end of the strand passed around it and secured with a guy clamp.

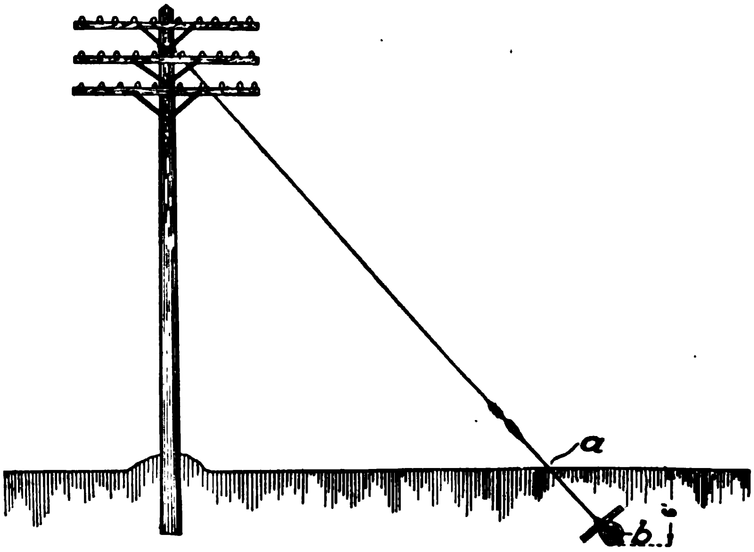
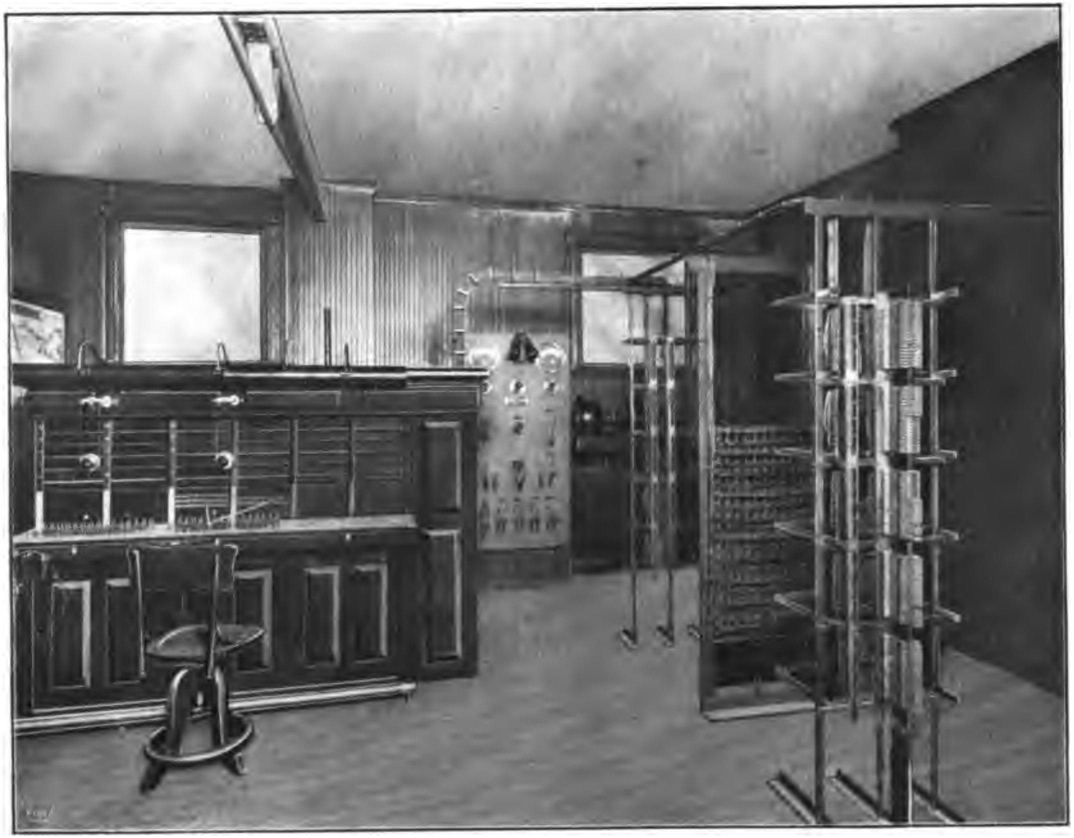


Fig. 114.

The method of securing the guy strand to the pole or stub is shown in detail in Fig. 112; and that used in fastening it to the anchor rod, in Fig. 113.

The methods illustrated in Figs. 110 and 111 are applicable to side guying and head guying at the end of a line. In head guying and back guying, the guy strand is fastened to the next adjacent pole at a point about 4 feet from the ground.

In Fig. 114 is shown another method of securing the guy strand. A guy rod *a* is secured to an anchor-log *b* sunk 6 feet in the ground. On the upper face of this log is secured a piece of plank 2 feet by 2 inches and of the same length as the log. This is done to afford additional resisting surface against being pulled out. The "eye" end of the rod is allowed to project about one foot above the ground, and the guy strand is fastened to it in the manner already described.



COMPLETE COMMON BATTERY SYSTEM.

Installed in the Kellogg Switchboard and Supply Co. Factory.

In Fig. 115 is shown the method of securing the guy strand when the ground is rocky. A hole is drilled in the rock at the angle shown, and the rock eye-bolt is driven into it, the strand being attached to the "eye" end in the same manner as that described for the guy rod. The hole in the rock should be of such a size as to give the eye-bolt a binding fit. The detail of the eye-bolt with the attached strand is shown to the right.

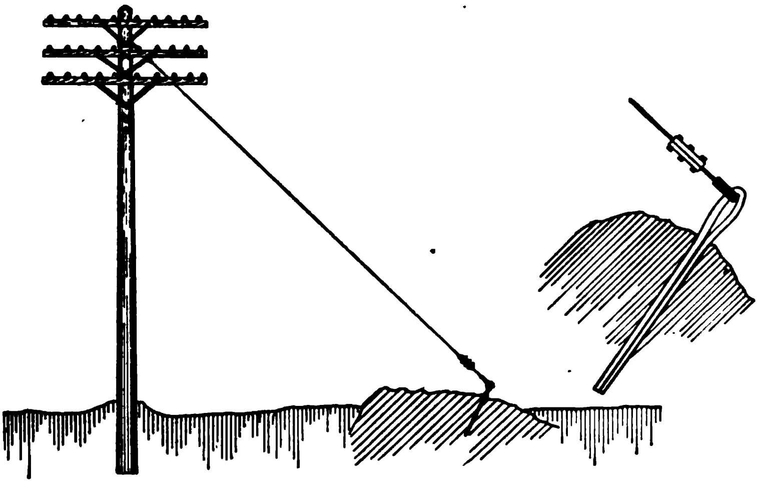


Fig. 115.

In addition to the directions for placing guys already given under the heading of "Laying Out the Line," the following should be noted:

When a line turns a corner, both straight sections should be head-guyed and side-guyed as shown in Fig. 116.

In crossing a road, each turning pole should be double side-guyed, or guyed on both sides, and also head-guyed.

The two poles next to the turning poles should be head-guyed.

Terminal poles on long spans—200 feet—should be head-guyed, and, if possible, side-guyed in both directions.

The adjacent poles should be head-guyed to the terminal poles.

In passing through hilly country the poles should be head-guyed as shown at *a* and *b*, Fig. 117, so as to overcome the downward strain.

Lines of four cross-arms or more should be double side-guyed every quarter of a mile, and double head-guyed every half mile, in addition to whatever other guying may be needed.

The method of guying in hilly country is shown in Fig. 117. Here the downward strain would pull poles 2 and 3 over towards pole 1 were it not for the guy *a* securing pole 2 to pole 3, and guy *b* securing pole 3 to pole 4. In many cases it is convenient to guy to trees. Particularly is this so in the case of side-guying. When trees are used as guy stubs, the following precautions must

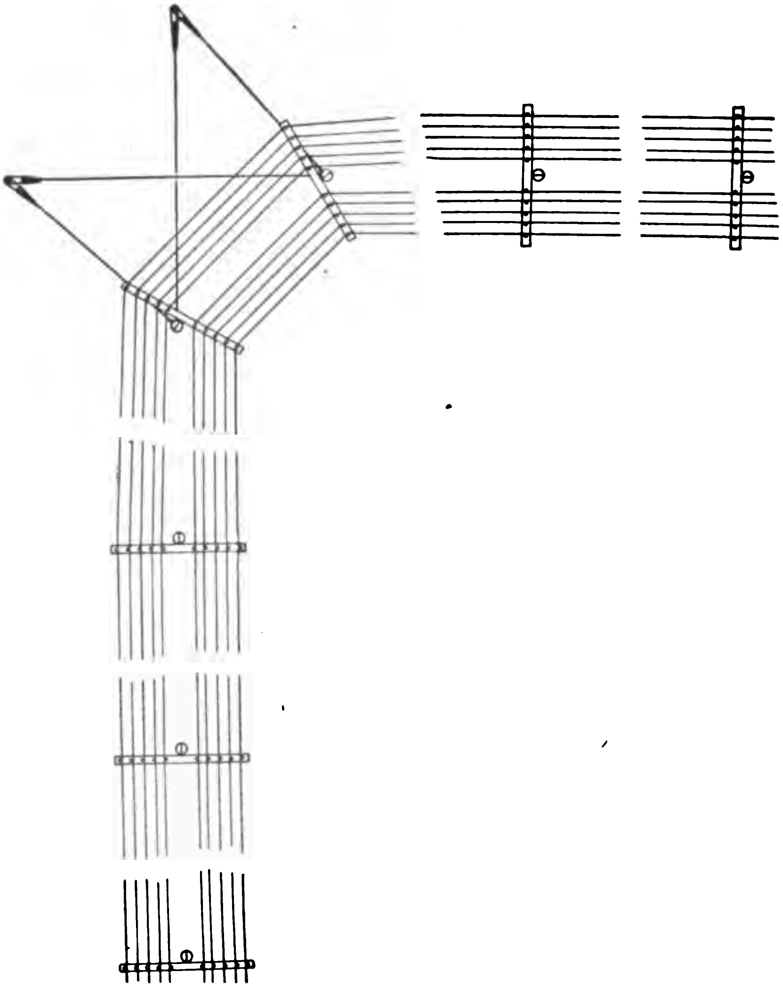


Fig. 116.

be taken: A tree must be selected which is perfectly secure and which is large enough in diameter to stand the strain. The bark must be protected by means of lagging made of pieces of wood about 1 foot long and 2 inches by 2 inches. These are placed against the tree, the guy strand being wrapped around them and secured in the usual manner. In guying it must be remembered that the strain on the strand can be resolved into two components, one vertical, or down the pole, and the other horizontal, or at right angles to the pole. It is this latter that is useful; and to make its amount as large as possible in proportion to the total strain, the strand must be secured at a point as far from the foot of the pole as possible.

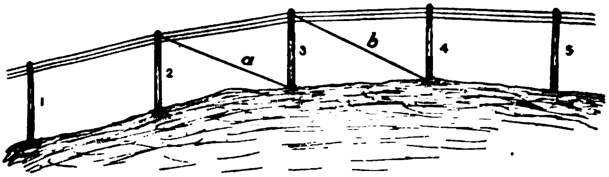


Fig. 117.

TELEPHONE CABLES.

Types of Cable. There are three types of cable used in telephone line construction, each one peculiarly suited to the conditions it is called upon to meet. Considered with regard to the nature of the insulating material, two of these classes may be merged into one, leaving only two distinct kinds of cable when classified in this way. The conductors of cables are insulated either with **paper** or with a compound of **rubber.** When cables were first introduced into telephone work, the conductors were insulated with cotton braid saturated in rosin oil. It was found, however, that a better insulation could be obtained by the use of paper, besides securing the additional advantages of reduced cost and reduced size of cable. Cotton insulation, therefore, so far as cables used in line construction are concerned, is a thing of the past.

Paper-insulated cables are made in several ways, but are comprised in two great classes, **dry core cables** and **saturated core cables.** In the manufacture of dry core cables, as the name indicates, the conductors are wrapped with dry paper, and are subjected to no further treatment except baking. In the manufacture of saturated core cables, the conductors, with their paper insulation, are saturated with melted paraffine. The advantage of the latter treatment lies in the fact that, should the cable be subjected to moisture, the paper will not absorb it as it does in the case of dry core cables. As a general thing the dry core cable is used on underground lines, while the saturated core cable is used on aërial lines.

Paper-insulated cables — or "paper cables," as they are called — are constructed in the following manner: The conductors, consisting of No. 19 B. & S. gauge soft-drawn copper, are covered with a wrapping of Manila paper of about the thickness used by shopkeepers in wrapping goods. In order to overcome the mutual induction that would otherwise be present, each pair of conductors forming a circuit are twisted together into a strand, the length of the twist not exceeding 6 inches. These strands are laid up in layers around the center of the cable, each layer being wound spirally around the center in the opposite direction to that of the next adjacent layer. In order to distinguish one of the conductors in a strand from its mate, the insulation on one of the wires is marked in some peculiar way. The standard cables made by the Western Electric Co., for instance, have one conductor covered with red paper, and its mate covered with white. The cable thus consists of a number of red covered conductors each twisted with a conductor covered with white paper. Some manufacturers, notably the American Electric Works at Providence, R. I., have a red thread in the paper on one conductor, and white paper on its mate.

When the pairs of conductors have been arranged in layers as described, the whole is bound with cotton thread saturated in paraffine. If a dry core cable is intended, the whole is baked in a suitable oven in order to expel all moisture from the paper; while, if a saturated core is wanted, the cable is immersed in melted paraffine.

This work having been finished, the cable is ready for the lead sheath. This sheath consists of a lead pipe $\frac{1}{8}$ inch in thickness and having an inside diameter equal to that of the cable. It is forced on under pressure, cooling as it goes into place. When the lead sheath has been placed, the ends, in case of a dry core cable, are saturated in paraffine for a distance of 2 feet, to prevent moisture entering. The sheath is then sealed up at both ends, and the cable is ready for market. Standard lead cables of both types are made in the following sizes and of the outside diameters indicated in Table XIII:

TABLE XIII.

Sizes of Standard Lead Cables.

Number of Pairs of Conductors.	Size of Wire. B. & S. Gauge.	Outside Diameter.	Length.
2	No. 19	1 inch	1,000 feet
5	"	1½ inches	1,000 "
10	"	1½ "	1,000 "
15	"	1¾ "	1,000 "
25	"	1⅞ "	1,000 "
50	"	2 "	800 "
100	"	2¼ "	800 "
150	"	2½ "	800 "
200	"	2¾ "	800 "

The New York Telephone Company have developed a cable in which No. 22 B. & S. soft-drawn copper is used and which is made in sizes of 300 and 400 pairs, each size having an outside diameter of 2½ inches. For underground lines in large cities, this type of cable is especially well adapted.

In Fig. 118 is shown a typical paper cable, with part of the sheath removed to show the successive layers, which appear at *a*, *b*, *c*, etc., going from the center outwards.

A paper cable manufactured by the Felton-Guilleaume Company possesses the same essential features as those already described, but is more economical in the use of insulating paper. It is shown in section in Fig. 119, together with a detail of the method of using the paper. It will be seen that the conductors of a pair are placed on opposite sides of a ribbon of insulating paper, and twisted together. A second ribbon of paper is then wound around the pair to insulate it from the other pairs. The whole is then bunched together, and covered with a lead sheath in the manner already described.

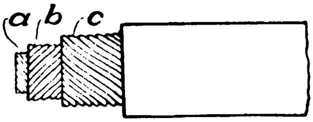


Fig. 118.

When cables were first introduced, the great drawback to their use lay in the high electrostatic capacity existing between the conductors. In the open-wire line this electrostatic capacity is reduced to a minimum by the great distance existing between the conductors. In the cable, however, where wires are bunched together, this separation does not exist and special precaution must be taken. Paper, on account of its porous texture, entraps within itself a large amount of dry air — a substance which, with the single exception of hydrogen gas, possesses the lowest electrostatic capacity of all known bodies. The specifications for dry core cables call for a capacity between each conductor and its fellows of .08 microfarad per mile. In actual fact, cables are constructed with a capacity of .06 microfarad per mile and even lower. Saturated core cables, for the reason that a great deal of the dry air is excluded by the paraffine, have a somewhat higher capacity. The specifications for these cables call for a capacity between each conductor and its fellows of .175 microfarad per mile, which requirement is easily complied with by the manufacturers. Each conductor should have a resistance of not more than 47 ohms per mile at a temperature of 60° F, and the insulation resistance of each conductor should be at least 500 megohms per mile. Cables of this type are made continually whose insulation resistance is 1,000 megohms per mile and higher.

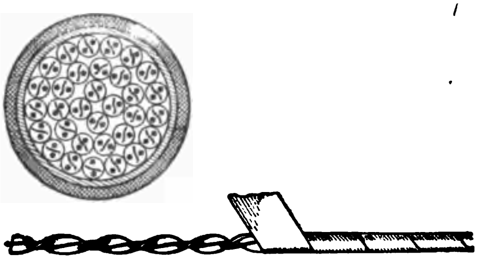
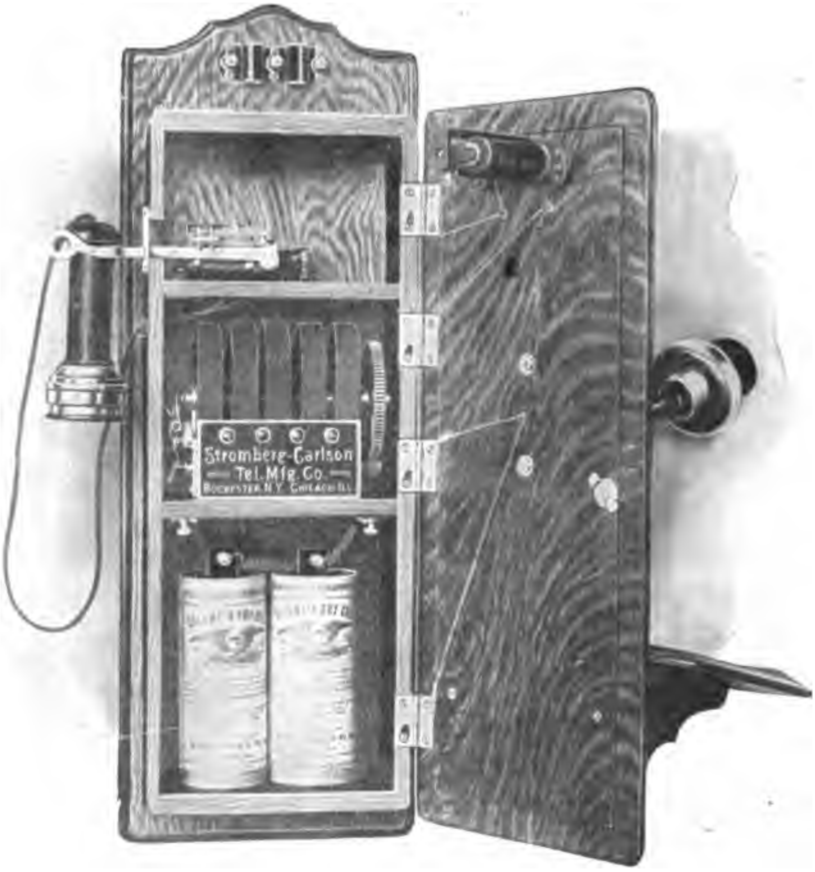


Fig. 119.

When lead-sheathed cables were introduced, the sheath was made at first of pure metal. It was found, however, that when these cables were laid in the creosoted duct tubing then in vogue, the dead oil of tar corroded the lead. By an admixture of 3 per cent of tin this liability to corrosion was found to be overcome, so that today all lead sheaths are made with an admixture of 3 per cent of tin. Some manufacturers go so far as to place a layer of tin outside the lead, but this is not necessary. Lead-sheathed cables are always constructed with two spare pairs to be used in case of emergency.



DRY BATTERY TYPE BRIDGING TELEPHONE.

Stromberg-Carlson Telephone Mfg. Co.

TELEPHONY

PART III.

TELEPHONE LINES.—(Continued.)

Rubber-insulated cables, with the exception of submarine work, are used exclusively for aërial work. They comprise two classes known as **bridle cables** and **tree cables**, which differ but slightly. For local work, the sizes of the wires are No. 18 B. & S. and No. 16 B. & S. The Long Distance Company use No. 12 B. & S. The copper is hard-drawn and covered with a coating of tin. The insulation consists of a rubber compound $\frac{3}{16}$ inch in thickness, which is covered with a layer of tape. In some rubber cables the conductors of a pair are covered with differently colored insulation, one conductor, for example, being covered in red and the other in a drab color. It has been found, however, that coloring matter injures the texture of the compound, rendering it so soft as to be easily peeled off with the finger nail. Its use, therefore, is not to be recommended. The pairs are twisted together, and laid up around a central core of jute, called the **filling**. The whole is then bound together with a winding of jute, called the **serving**, and is saturated with rosin oil. Over the serving are wound two layers of heavily tarred tape. In the case of the tree cable, an additional covering of heavily tarred cotton braid is placed outside of the tape. The conductors of these cables should have an insulation resistance of 250 megohms per mile after being immersed in water for 48 hours at a temperature of 60° F. This requirement is easily met by the manufacturers. The electrostatic capacity of this class of cable is very high, but as it is used only in very short lengths, this feature is of no material importance. Rubber cables are made in the following sizes: 3-pair, 6-pair, 11-pair, 15-pair, 20-pair, and 25-pair. Their diameters vary from about $\frac{1}{2}$ inch to $1\frac{1}{4}$ inches.

Stringing Aërial Cables. Aërial lead-covered cables are strung on the poles in connection with the open wires, to increase the capacity of the line. The method of construction consists in hanging the cable to a suspension wire supported upon the poles. There are many ways of supporting the suspension wire **or messenger wire,** as it is sometimes called. The most approved method will be described. The suspension wire is constructed of galvanized steel wires twisted together in the same manner as that described for guy rope. Three sizes are used in standard construction, which are of the following diameters and weights: $\frac{1}{4}$-inch diameter, having a weight of $11\frac{1}{2}$ lbs. per 100 feet; $\frac{5}{16}$-inch diameter, having a weight of 21 lbs. per 100 feet; $\frac{1}{2}$-inch diameter, having a weight of 51 lbs. per 100 feet. The first has a breaking weight of 1,750 lbs.; the second, a breaking weight of 3,300 lbs.; and the third breaks at 8,320 lbs. For special work, such as supporting extra large cables, or on extra long spans, special sizes of suspension wire must be used. The above sizes are standard.

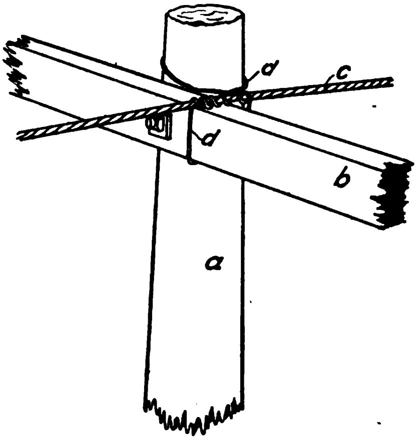


Fig. 120.

The first method adopted for supporting suspension wire was next to the pole, and to lash it to rest it upon the cross-arm, firmly with marlin as shown in Fig. 120, where the pole is shown at *a*, the cross-arm at *b*, and the suspension wire at *c*. The marlin lashing is shown at *d*, and is wrapped around the cross-arm and suspension wire and secured to the pole. This construction, however, was found to be rather crude. Not only did the suspension wire cut into the cross-arm, but an additional disadvantage lay in the fact that the arm was subjected to too great a load.

The next method devised was to drive a pole step securely into the pole just below the bottom gain, rest the suspension wire on it, and securely fasten the wire with marlin, as shown in Fig.

121. While this change was a step in the right direction, there still remained the disadvantage of having the suspension wire resting on so small a bearing surface as the pole step. An improved method is to drill out the center hole of a guy clamp to a sufficient size to take a cross-arm bolt, and to secure the clamp to the pole by means of such a bolt driven through the pole in the usual manner. The suspension wire is then passed through the upper groove, and securely held in place by the two end bolts. This construction is shown in Fig. 122, where *a* represents the pole, *b* the suspension wire, *c* the cross-arm bolt passed through the center hole of the guy clamp, and *d d'* the two end bolts securing the suspension wire.

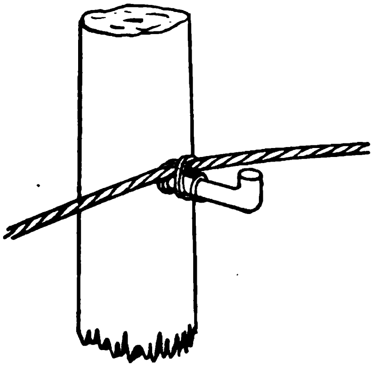


Fig. 121.

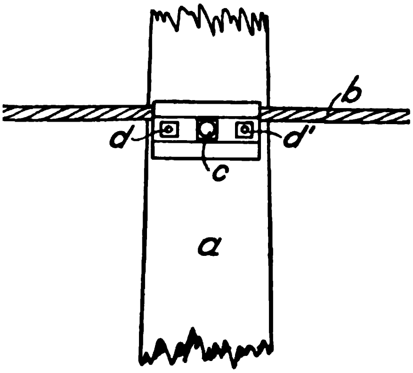


Fig. 122.

A special form of hanger has been devised to take the place of the guy clamp. It is shown in Fig. 123. It consists of a flat hook *a* made of ½-inch galvanized wrought iron about 4 inches wide. It is fastened to the pole by means of a cross-arm bolt *b b*. The suspension wire is shown in section at *d*; and the retaining bolt, which prevents the wire from getting out of place, is shown at *c*. On account of the strength, simplicity, and cheapness of these hooks, this method is the one most to be recommended. A more elaborate method, and one to be recom-

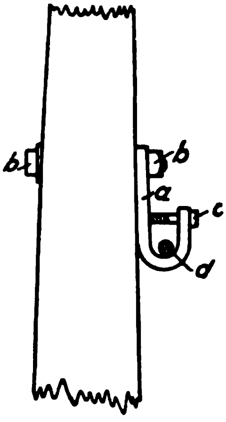


Fig. 123.

mended where a large number of cables are to be supported on one pole, is to have a specially designed cable cross-arm. One of these is shown in Fig. 124, and consists of a steel angle $4\frac{1}{2}$ inches by 3 inches, constructed of $\frac{3}{4}$-inch stock. The $4\frac{1}{2}$-inch face is set in the gain and is fastened to the pole and braced in the usual manner. The horizontal face is for the support of the suspension wire, and in it are drilled holes, *a*, *b*, etc., the extreme one being 4 inches from the end of the beam on each side. The other holes are spaced 6 inches, with the exception of the two holes nearest the pole, which are 20 inches apart. The holes on the horizontal face are of the proper size to take a $\frac{5}{8}$-inch bolt of special length to secure the guy clamp to the arm. The guy clamps are secured to the arm by this special bolt passed through their center holes, and the suspension wires are passed through one of the grooves in each clamp and secured by the two end bolts. The suspension wire should never be spliced; but when the end is reached it should be secured to the nearest pole in the same manner as that adopted for guy strand, and a new run begun. Suspension wire is usually furnished in lengths of 1,000 feet, and when it is to be strung it is run off on the ground, and then hoisted up at each pole. The suspension wire having been strung, pulled tight with a block and fall, and fastened, the work of running the cable should be started. Great care must be taken to protect the sheath from abrasions or kinks.

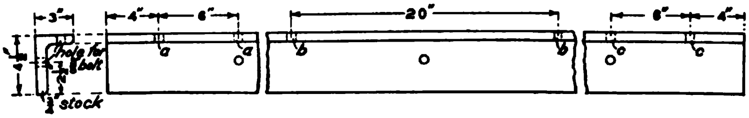


Fig. 124.

There are several good ways of stringing cable, but probably the best method to adopt is to mount the reel on a stout truck in such a manner as to allow it to unwind and let the cable run off. One end of the cable is fastened securely to the terminal point, and the truck is driven slowly ahead. A man seated in a boatswain's chair, which is mounted on wheels on the suspension wire, raises the cable up to the wire as the cable unwinds, and secures it temporarily at intervals of about 50 feet. As the cable unwinds, the truck is driven ahead so that it is always about 50 feet in advance of the man in the boatswain's chair. When the cable is very heavy, and therefore difficult of manipulation by the man in the boatswain's chair, a better method is to follow that shown in Fig. 125. The reel is mounted as shown, so that it unwinds from the upper side. The suspension wire is carried down to the ground at an angle of about 45°, as shown at *a*, and is securely fastened. It is better, but not necessary, to have two rollers *b b'* over which the cable runs as it passes off the reel. A rope strung

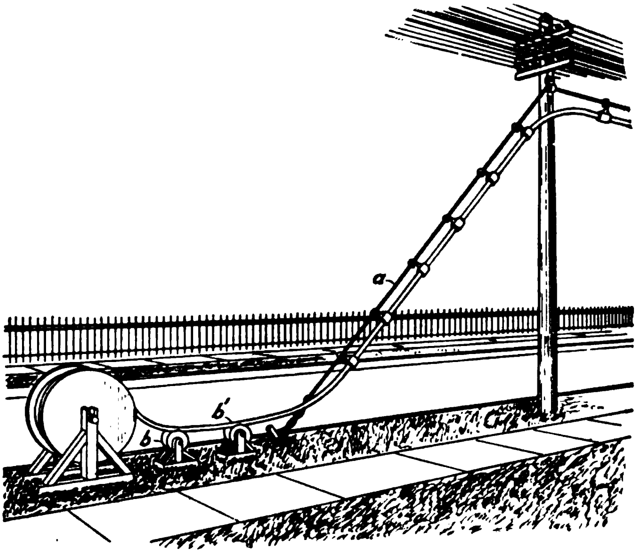


Fig. 125.

over the cross-arms in much the same manner as that described for stringing open wires, is attached to the end of the cable and serves to drag it along. As the cable begins to ascend, a man stationed at that point attaches it to the suspension strand by means of suitable hangers, which move along the suspension strand with the cable. As the cable reaches the cross-arm, a man on the pole lifts the rope off and guides the hangers past the point where the suspension wire is fastened. At the next pole the same process is repeated, this being continued until the cable has been strung. One disadvantage in this method lies in the fact that it requires the services of a man constantly at each pole.

Another method, and probably the best of all, is to carry the cable in a stirrup attached to a wheel that runs along the suspension wire. The wheel is guided around the point of support at each pole.

Cable Hangers. The old method of supporting cables was to wrap a stout marlin string around the cable and the suspension wire. This was done by an instrument called a **spinning jenny,** consisting of a hollow cylinder made in two halves. The section is shown at *a*, Fig. 126, and the end view at *c*. Attached to one end of the cylinder is a lug *b*, to which is attached the rope by means of which it is drawn along. The hole through the center of the cylinder is large enough to accommodate the cable and the suspension wire. The marlin is wound in layers on the jenny, which is placed over the cable and the suspension wire, the two halves being held together by a suitable device. One end of the marlin is fastened securely and the jenny is pulled forward. As it moves, the marlin is unwound, and wraps itself around the suspension wire and the cable, thus holding the two together. The action is shown in Fig. 127. Recently, however, this method has been superseded by using some form of metallic hanger. The most approved type of this style of hanger is shown in Fig. 128. It is made of sheet iron tinned, and is called the **metropolitan clamp.**

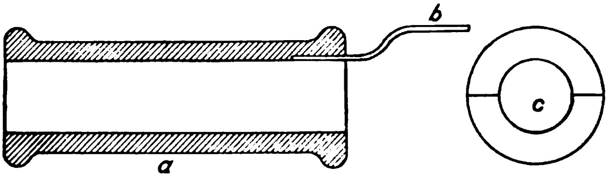


Fig. 126.

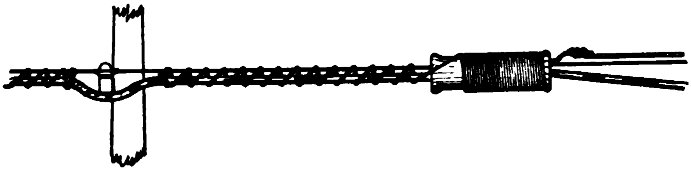


Fig. 127.

The cable sheath should be specially protected from abrasions at points where it passes poles. During high winds the cable sways to some extent, and a certain amount of rubbing between the cable sheath and the pole takes place. The necessary protection from abrasion is given by fastening wooden lagging about the cable with marlin, as shown in Fig. 129, where *a* denotes the suspension wire, *b* and *b'* the hangers, and *c* and *c'* two wooden strips fastened on opposite sides of the cable by the marlin. A better way is to give the cable at this point a heavy wrapping of marlin wound close together and in several layers. This is more flexible than the wood, and forms a better cushion.

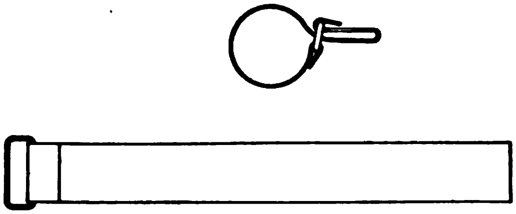


Fig. 128.

Underground Cable Lines. In large cities and in many towns, laws exist against the building of aërial lines, whether open-wire or cable. In many residential suburbs, the inhabitants object to the building of aërial lines on account of the unsightly appearance of the poles. The number of underground lines in use is accordingly increasing at a very rapid rate from day to day. While underground wires are much more costly to build than aërial lines, they are proof against injury by storms.

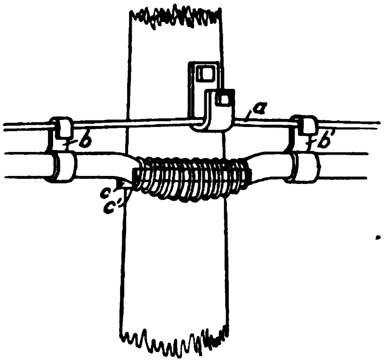


Fig. 129.

When telephone cables were first put underground, an open trench was dug and the cable was laid in, being surrounded with a mixture of cement and sand. The trench was then filled. It was found, however, that if a cable became defective, the whole trench had to be dug up in order to replace it. The necessity for some form of duct into which the cables could be drawn was apparent. Disregarding the experimental work that proved worthless, the first form of duct used was constructed of creosoted pine in the shape of an open trough. This trough was laid in the trench, the cable being laid in it and the earth then filled in. This construction proved to be equally defective with the open trench in the fact that the cable could not be drawn out without opening the trench. The next method devised was to construct a circular duct of the form shown in Figs. 130 and 130 *a*. The standard size consists of a stick of timber 8 feet long, sawed square, with edges 4½ inches. Through the axis is bored a hole 3 inches in diameter. One end of the stick is cut with a tongue, shown at

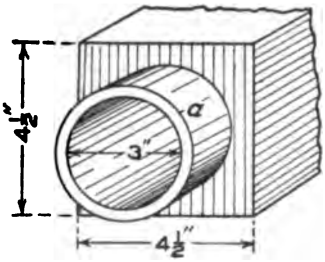


Fig. 130.

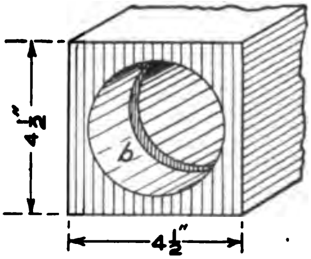


Fig. 130 *a*.

a, Fig. 130 ; while the other end is cut with a recess, shown at *b*, Fig. 130 *a*. In construction the tongue of one log fits into the corresponding recess in the next succeeding log, and the joint is made secure by pouring in hot pitch. These logs, or ducts, called **pump logs** by some, are impregnated with creosote in the same manner as the cross-arms. The method adopted in constructing subways with this form of duct tubing, is illustrated in Fig. 131. A trench is first dug, varying in depth from 3 to 6 feet according to the grade of the street. Creosoted planks 2 inches thick, shown at *a a′*, are laid in the bottom of the trench for a foundation, upon which is placed the duct tubing. In the present case there are 12 ducts being laid, 3 rows of 4 ducts each. On top of the upper layer is laid a roofing of creosoted planking; and between the sides of the ducts and the trench are placed joists, one of which is shown at *c*, to prevent lateral motion. The earth is then filled in and packed down. One of the men on top of the ducts will be seen with a hammer, in the act of driving home a joist. The creosoted ducts about to be used are shown piled up at the side of the excavation at *b*. The depth of the trench should be so regulated that the top planking is at least from 2½ to 3 feet below the surface of the road.

Another form of duct tubing which has come into use since the introduction of the pump log, is the cement-lined iron pipe. The method of constructing it is shown in Fig. 132. It consists of a tube 8 feet long constructed of wrought iron .018 inch thick, the seam being fastened by rivets placed 2 inches on centers as shown at *a a'*. The tube is lined with a wall of Rosendale cement about ⅝ inch in thickness, shown at *d*. Into one end of the tube is fitted a casting of the form shown at *b;* while into the other end is inserted a casting of the form shown at *c*. The cast-

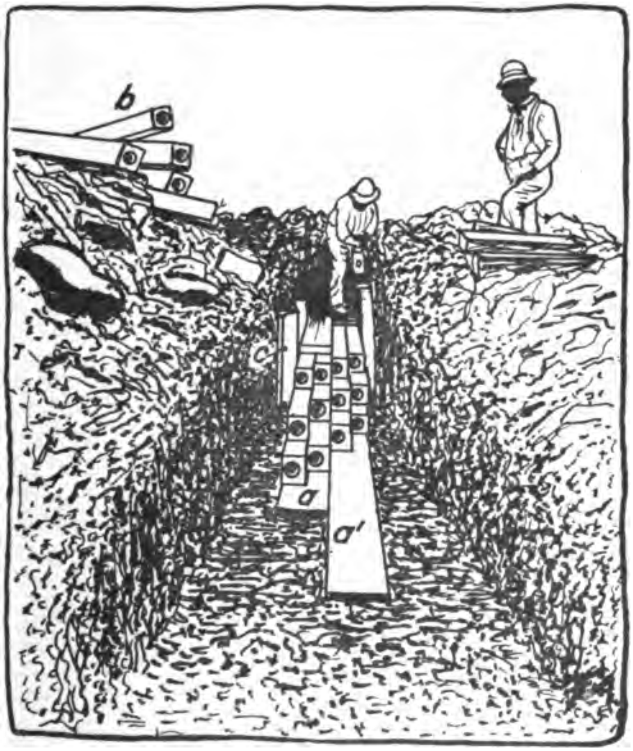


Fig. 131.

ing *c* fits securely into the opening at *b*. The standard size of this tube has a 3-inch hole.

In setting this conduit the ends are butted together, the sockets making secure joints, and yet allowing enough play for slight bends. When short curves have to be made, bent tubes must be used. This conduit is laid in a trench, in the bottom of which is placed a bed of concrete about 6 inches thick. The first layer of tubes is covered with a layer of cement mortar, reaching to the height of about 1 inch above the top of the tubes, the second layer being laid upon this. This process is repeated for each succeeding layer. In Fig. 133 is shown the method of constructing a subway with this form of duct. It will be seen that

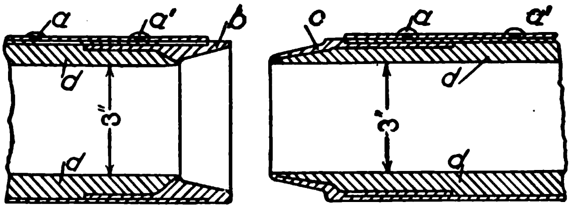


Fig. 132.

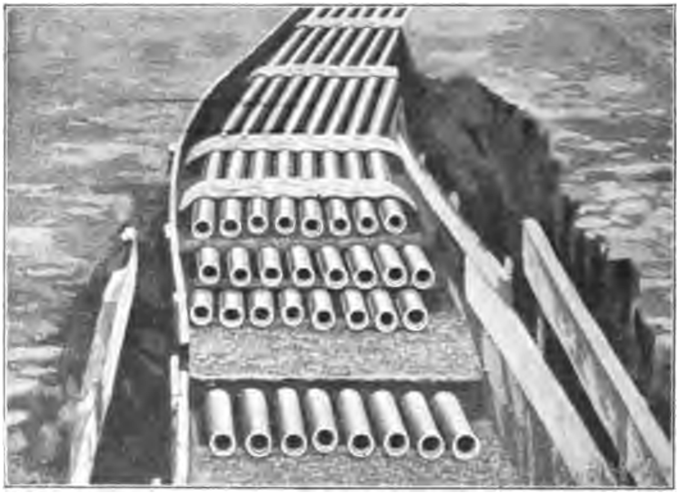


Fig. 133.

the sides of the trench are walled in with rough planking, which acts as a retaining wall for the mortar and the concrete. On the top of the upper layer of ducts is laid a layer of concrete from 4 to 6 inches in depth. The earth is then filled in and packed down tightly.

The two forms of conduit just described have been largely superseded by those made of vitrified clay or terra-cotta. The vitrified duct has the advantages of cheapness, ease of construction, and high insulation, besides being absolutely proof against all forms of chemical action. One form of this duct is shown in Fig. 134. It is made in sections 2 feet in length. The edges of the hole are beveled to facilitate the drawing in of the cable.

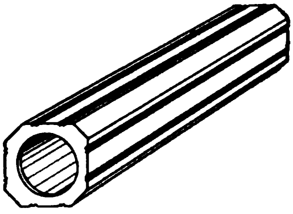


Fig. 134.

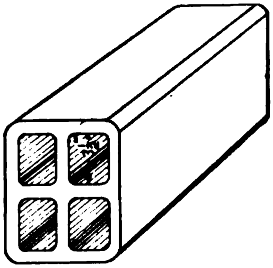


Fig. 135.

Another and better form of this class of conduit is shown in Fig. 135. It consists of sections of 4 ducts of the size indicated. The great advantage of this conduit lies in the fact that with it 4 ducts can be laid with the same amount of labor that would otherwise be necessary in laying only one.

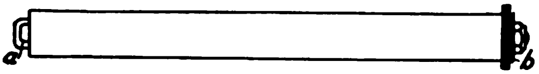


Fig. 136.

This duct is laid in a bed of concrete as is the case with the cement-lined pipe, and a cement casing is built all around. In laying the duct a mandrel, shown in Fig. 136, is used. It is of wood, 3 inches in diameter and 30 inches long. At one end is attached an iron eye *a*, and at the other end is a rubber gasket *b* whose diameter slightly exceeds that of the interior of the duct. One of these mandrels is placed in each duct as the work of laying is begun; and as successive sections are laid around it, it is drawn forward so that ⅔ of its length is constantly projecting beyond the end of the last duct laid. By this means good alignment is secured, and whatever dirt may have accumulated in the ducts during the process of construction is swept out. In Fig. 137 is shown the process of construction as followed with this class of duct.

On first consideration it might seem advantageous to construct subways that would be continuous from the point of starting at the exchange to the point of termination, wherever that might be. Such a course, however, would necessitate hauling the cables in in one piece, which, even if it were possible, would be difficult and very costly. It has been found best to break the subway every 350 to 400 feet by a suitable chamber dug in the earth, called a **manhole.** The manhole also serves to furnish a point of inspection. Still another advantage gained by having a manhole lies in the fact that should a cable become defective at any point, it is necessary to remove only the section between the two adjacent manholes. If the cable were laid in one piece, it would be necessary to remove the whole cable. The construction of manholes is very important, and should be done in the following manner:

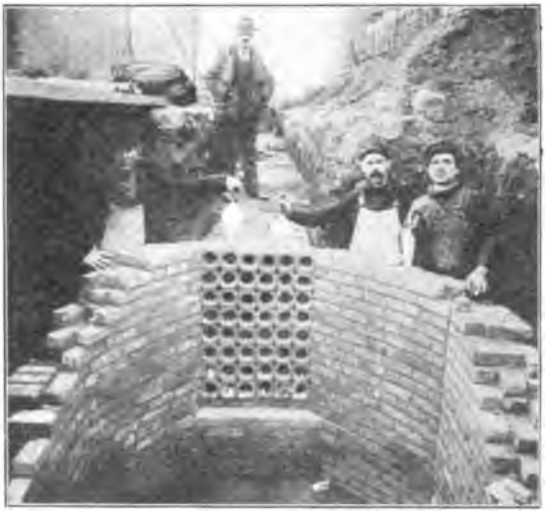


Fig. 137.

The size of the manhole depends upon the number of ducts, but it should be large enough to allow a man to work with advantage. The usual form is that of a rectangle 8 feet by 4 feet, and about 6 feet deep. The walls are made of brick. In Fig. 138 is shown the elevation of a manhole, in which *a a'* denote the brick wall. The bottom of the manhole, in the best construction, is made of cement and concrete mixed in the following proportion:

Good Cement	**1 part.**
Sand	**2 parts.**
Broken Stone	**5 parts.**

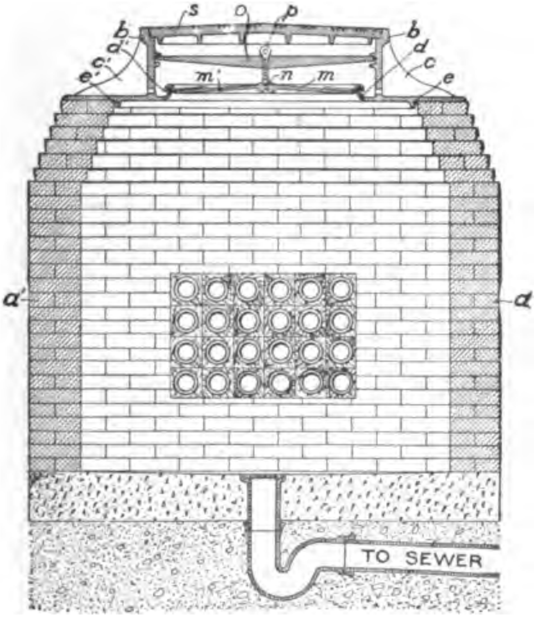


Fig. 138.

This is laid to a depth of 8 inches. In some cases the manhole is drained off by a pipe connection to the sewer, having the usual trap to prevent the entrance of the sewer gases. The concrete foundation and the sewer connection are not absolutely necessary. On top of the brick work is placed a cast-iron manhole head shown at *b b*. The bottom of this casting is equipped with a circular flange *e e'*, which, when in place, lies up against the sides of the brick wall and prevents lateral motion. The casting is reinforced by two flanges *c c'*. A second circular flange *d d'*, projecting upwards, serves as a rest for the inner cover *m*, whose edge is grooved to fit. A circular rubber gasket is placed in this flange, making, when the cover is in place, a water-tight joint. In the center of the cover is a cup-shaped depression *n*, into which fits the bolt *p* of the locking bar *o*, which is itself held in place by a groove in each side of the casting. The outer cover, shown at *s*, fits on a seat at the top of the casting. This cover is heavier than the inner one, being strong enough to bear the weight of heavy trucks; it should fit securely on the seat and not rattle. The ducts are shown coming through the side of the wall.

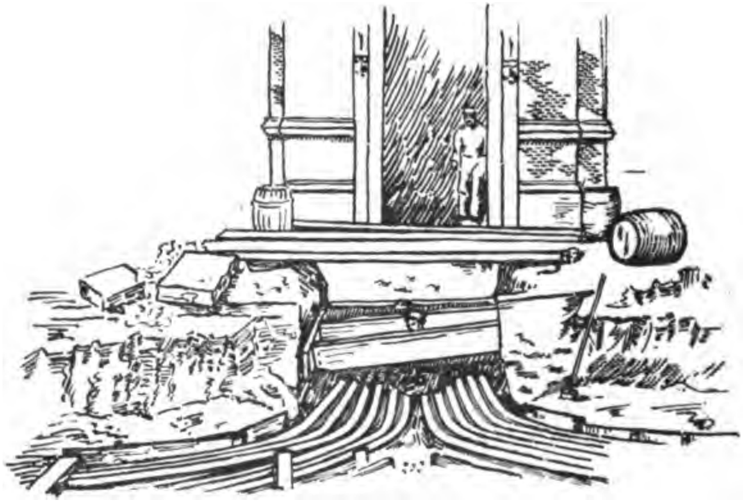


Fig. 139.

In Fig. 137 is shown in the foreground a manhole in course of construction. Where the manhole is large, as in the case shown in the figure, it would be impossible to corbel the brick work sufficiently to make the opening at the top small enough to support the manhole head. In this case two iron girders are laid across the top, and the head is supported on them, the open spaces being filled in with flat brick arch work. Fastened to the sides of the hole through which there are no ducts penetrating, are two stout planks to which are attached several wrought-iron hooks for supporting the cables. These are not necessary, but usually accompany the best construction.

Manholes are sure to collect more or less gas, which is drawn in through the ducts. Gas and sewer pipes sometimes pass through the manholes, and the gas escapes into them in this way. Before any work is done in a manhole, therefore, it should be allowed to stand open for a while in order that the gas, if there be any, may escape. The gas can be removed with a pump, or by means of a contrivance like an umbrella with a string attached to the handle. This is lowered into the hole and then pulled up smartly, the resistance of the atmosphere opening it and thus enabling the gas to be drawn out. A very good method of securing good ventilation in a manhole during the process of work, is to erect one end of a long, narrow sheet about 6 feet above the side of the hole opposite that from which the wind is blowing, and to allow the other end to hang down into the hole. The wind, striking this sheet, is deflected downward into the hole, and forming an eddy forces up the gases that may be lodged inside. To guard as much as possible against the collection of gases in manholes, the ducts not in use have their ends closed with wooden plugs.

The subway is brought into the cellar of the building used for the central office, in order that the lines may be brought in a suitable manner to the switchboard. In doing this the ducts are either terminated in a vault under the sidewalk, or are carried through the cellar wall itself. In Fig. 139 is shown the method of laying the ducts into the exchange building. They come from both directions, bend at right angles, and pass through the foundation wall directly under the hall door. In large exchanges where a great number of ducts terminate, the construction necessary for the proper handling of the cables is sometimes very elaborate. In Fig. 140 is shown a system of piping devised for continuing the ducts from their point of termination in the cellar wall to the place where the cables are to be distributed, and for arranging them in the proper order to facilitate this work. It consists of a number of iron pipes *a a′ a″* etc., which run from the cellar wall *c* to the point of distribution. They are supported upon two brick piers, one of which is shown at *b*, and the other at *b′*. The cables emerging from these tubes are shown at *e e′* etc.; and the plugged ends of those not in use, at *m m′* etc. This system has been installed in one of the largest exchanges in New York City.

Drawing in Cables. The subway being constructed, everything is in readiness for the drawing-in of the cables. The first step in this direction is to carry a rope through the duct into which the cable is to be drawn, from one manhole to the other. The old way of doing this work was called **rodding**, and consisted in pushing a number of rods through the duct, the end of each being screwed into the end of the one directly in front of it, until enough had been introduced to reach from one manhole to the other. A string was then attached to the last rod, and the rods were pulled out of the duct and unscrewed at the opposite manhole. When the last rod was reached, the string was untied. To the opposite end of the string was then fastened a stout rope, which was in turn pulled through. A better way, and one now practiced altogether, is to thread a string through each duct as it is being laid, and fasten the ends in each manhole so that they cannot be accidentally pulled out. A stout rope is then attached to the end of one of these strings and pulled through. The cable is in turn pulled through by means of this stout rope, in the following manner:

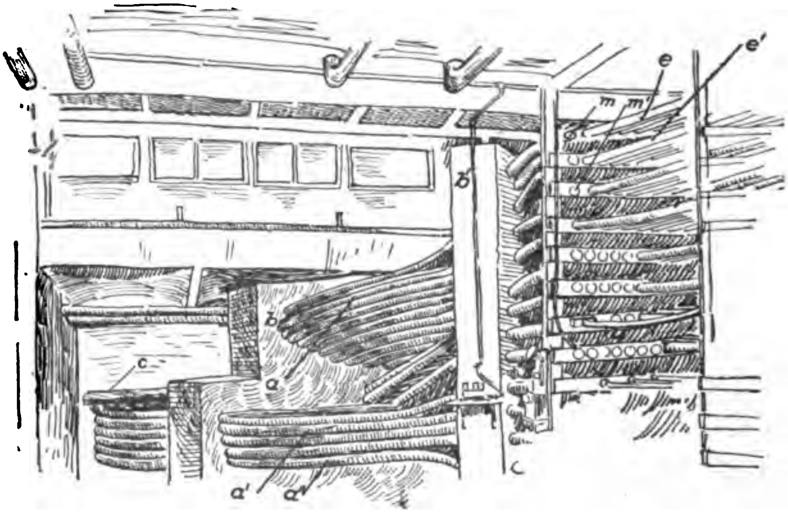


Fig. 140.

The reel containing the cable to be drawn in is mounted on the edge of the manhole, as shown in Fig. 141, in such a manner as to allow the cable to unwind from the bottom. Care must be taken to keep the sheath from touching the sharp edge of the hole at *a*, and for this purpose a man must stand in the hole and "feed" the cable in. The stout rope is fastened to the end of the cable in one of several ways, all of them good and yet all of them possessing disadvantages. One method, illustrated in Fig. 142, consists in fastening over the cable-end a wrought-iron clamp such as that shown in the figure, by means of screws passed through the holes and driven into the cable. The rope is fastened to the eye-piece *a*, and the cable is then drawn through the duct. Another method is to cut away the sheath for a length of two feet, and, bunching the conductors together, bend them back in the form of an eye, fastening them to the sheath, as shown in Fig. 143. Still another way is to wind around the sheath a network of iron wire, leaving an eye at the end for the attachment of the rope. All these methods require a good deal of time, and the first two necessitate wasting about 2 feet of the cable.

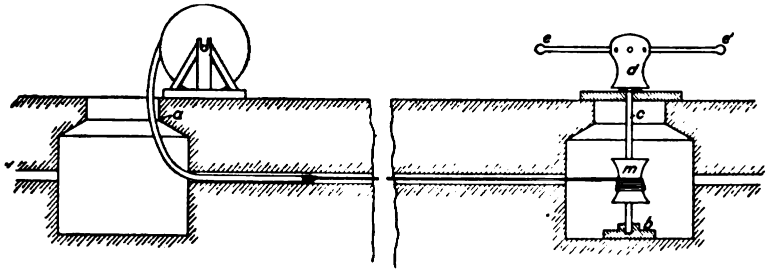


Fig. 141.

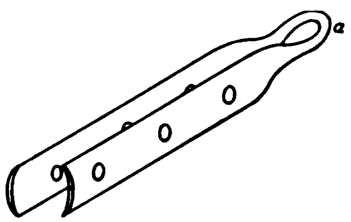


Fig. 142.

The rope being fastened to the cable, the latter is drawn through the duct by means of the capstan *d*, Fig. 141 mounted on the shaft *c* that carries the drum *m* about which the rope is wound. The capstan is turned by men pushing on the capstan bars, two of which are shown at *e* and *e'*. Sometimes horse-power is used to

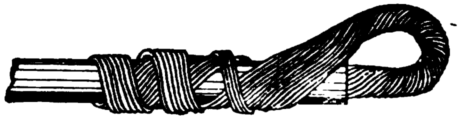


Fig. 143.

turn the drum, and one company has used a portable engine to perform this work. There seems, however, to be no indication of these methods coming into general use. In pulling in the length of the cable in the section between the central office and the first manhole, the reel is mounted in the central office and the pulling is done at the manhole.

Splicing. It has already been said that cables, whether underground or aërial, are strung in sections. Aërial cables are furnished in lengths of 1,000 feet, while underground cables are furnished in lengths corresponding to the distances between the manholes along the line of subway, so that each section of cable stretches only from one manhole to the next. In order, therefore, that the conductors may furnish continuous circuits, those of one section of cable must be joined properly to those of the next adjacent section; and in order that moisture may not attack the cable at these points of junction, the lead sheath must be made continuous throughout the whole length of the cable. This work is called **splicing,** and is done in the following manner:

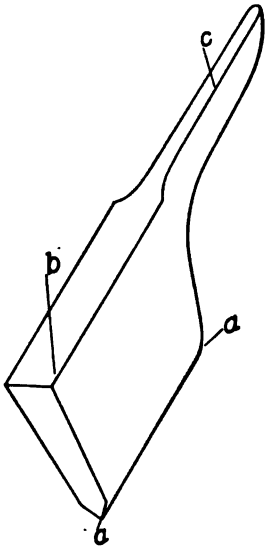


Fig. 144.

In stringing aërial cables, the ends of adjacent sections are allowed to overlap about 18 inches. In pulling in underground cables enough slack is left in each manhole to allow the cable to be placed on its proper supporting hook, or, wanting these, to lie loosely on the floor; also, as in the case of aërial cables, the ends of adjacent sections are allowed to overlap about 18 inches. In making a splice, the lead sheath on the two adjacent ends is cut away for about 2 feet, exposing the conductors. This work must be done very adroitly, so as not to cut the cotton wrapping or injure the paper insulation in any way. The tools needed for this work comprise a chipping knife and a hammer. The chipping knife, shown in Fig. 144, is a blunt heavy knife of wrought steel, with an edge *a a*, a broad back *b*, and a handle *c*. The method of cutting off the sheath is shown in Fig. 145. At a point about 2 feet from the end of the sheath, a groove *a* in depth about half the thickness of the sheath is cut all round. Starting at the end of the cable, holding the chipping knife as shown, and striking with the hammer in the direction shown by the arrow *c*, a longitudinal groove is cut to meet *a*. The arrow *b* shows the direction in which the knife blade is driven under the blows of the hammer, and it will be seen to be tangential to the conductors, so that, should the knife be driven too deeply, the insulation will not be injured. The lead sheath being thus removed, the cotton binding is wound tightly, and tied at a point about half an inch from its end, as shown at *a*, Fig. 146. The conductors are then spread out as shown at *b b′ b″* etc. Both ends are treated in this manner. A lead sleeve about 2 feet long, whose diameter exceeds that of the cable by from 1 to 2 inches according to the size of the cable, is then slipped over one of the ends, after having its edges tapered off with a file as shown at *c* in the figure. The two cable-ends are then brought near enough together to make the distance separating the ends of the sheaths about 18 inches. A pair from each cable is then taken, and the insulation is removed from the wires in such

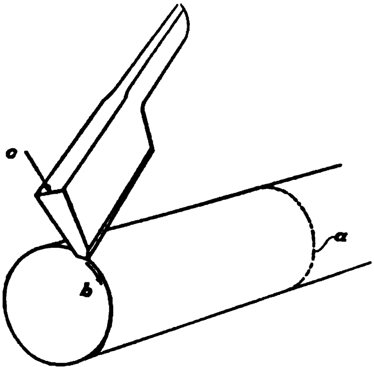


Fig. 145.

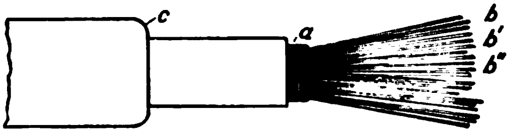


Fig. 146.

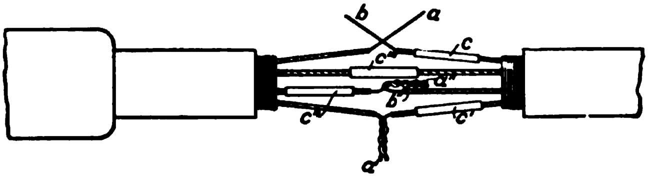


Fig. 147.

a manner that when the wires are placed as shown at *a* and *b*, Fig. 147, the ends of the insulation come together. A cotton sleeve 2½ inches long is then slipped over each conductor of each pair in one of the cables, as shown at *c c′ c″*. The red-covered wires are then joined together as shown at *a′ b′*, the joint being bent flat as at *a″ b″*, after which the cotton sleeve is moved over the joint as at *c‴*. The two white covered wires are then treated in the same manner, and this process is repeated until all the pairs of one cable have been joined to those of the next, red to red, and white to white. The appearance will be as shown at *a b c* etc., Fig. 148. Care should be taken not to have all the joints situated in the same locality. They should be spread out over a distance about 12 inches long.

To make a splice of this sort properly, the two cables should be laid horizontally and at the same level. Aërial cables naturally assume this position, and the cable splicer sits in a boatswain's chair hung from the suspension wire. In the case of underground cables, the best way is to place the end of each on a box or barrel. The conductors having been spliced as shown in Fig. 148, the next process is that of **boiling out.** For this purpose paraffine is heated in a metal trough over a portable furnace such as plumbers use. The paraffine should be thoroughly heated to expel whatever moisture may be contained therein, and in order to determine when it is hot enough the following points may be observed:

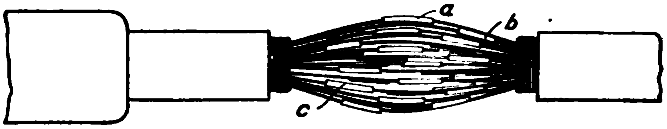


Fig. 148.

When paraffine becomes thoroughly melted it emits a light-colored smoke, which assumes a dark hue just before the paraffine bursts into flame. It is just when the dark smoke is first seen that the paraffine is at the right temperature to be used. A very simple and absolutely reliable test — one resorted to by cable splicers — is to spit into the paraffine. When the paraffine is hot enough the saliva is instantly thrown off.

When the paraffine is of the proper temperature it is poured over the splice with a ladle, and permeates all the spaces between the wires, making them air-tight and driving out whatever moisture may be contained in the insulation. It also saturates the cotton sleeving. When sufficient paraffine has thus been poured on, the conductors are bound together as tightly as possible with cotton thread, and the lead sleeve is moved up into place. The ends of the sleeve are hammered down to make a binding fit on the sheath, and a joint is wiped at each end. To do this a quantity of hard solder is melted in a pot over a plumber's furnace. The bent surfaces of the sleeve are rubbed with tallow, as are also the two sheaths, to a point one inch from the edges of the sleeve. The metal is then poured over the joints, and rubbed into place with a cloth pad, until a sufficient amount has been made to adhere to the two surfaces. It is then allowed to cool. At the completion of the work, the joint is as shown at $a\ b\ c$, Fig. 149, where the space occupied by the wires is shown between the lines $x\ x\ x$ etc., f, and f'. The sheath underneath the joint is enclosed in the lines $g'\ f'\ h'$ and g, f, and h. The edges of the sleeve are denoted by the lines $e\ e'$; and the spaces $m\ n\ m'\ n'$ are filled with the wiping metal.

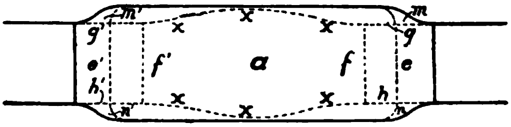


Fig. 149.

In splicing cables it is advantageous to preserve the position of the pairs throughout; that is to say, the middle pair in the first section is spliced to the middle pair in the second section, which in turn is spliced to the middle pair in the third section, etc. The first pair in the outer layer of the first section is spliced to the corresponding pair in the succeeding section, and so on. Observance of this rule facilitates the work of testing out after the cable has been finished.

In making a wiped joint the principal point to be guarded against is to keep the wiping metal from running under the sleeve onto the conductors, burning off the insulation, and ruining the cable. To this end the work must be done as quickly and adroitly as possible.

At the two terminating points of the cable — the central office and the end of the line — the conductors are spliced to wire having some form of waterproof insulation, or to a cable made up of such wires. The ends of the lead cable are then sealed up hermetically so that no moisture can enter. Such an arrangement is called a **pot-head**, and is made in the following manner:

The waterproof wire used for splicing to the conductors of the lead cable is No. 19 B. & S. gauge tinned, and has okonite insulation. The insulation is not covered with braid, as there is slight chance of mechanical injury. This wire is usually made into a cable, the pairs being bound together with waxed thread. Such a cable is called a **pot-head cable**, and the number of its pairs must always correspond to the number of pairs in the lead cable to which it is to be spliced.

The method employed in making the splice is the same as that already described. The lead sleeve is wiped at one end to the cable sheath in the usual way; the other end projects above the end of the sheath about 18 inches. After the splice has been boiled out in the usual manner, and the joint wiped, the space between the wires and the sleeve is filled with a compound of rosin and oil, which is heated into liquid form so that it fills not only the space between the wires and the sheath, but also that between the wires themselves. A sufficient quantity of the compound is poured in to fill the space up to the top of the sleeve. It is then allowed to cool, and in doing so hardens, and forms a solid mass that prevents any moisture from entering the cable.

Submarine Cables. As their name implies, submarine cables are used where it is necessary to carry the line underneath water, as, for example, in crossing navigable rivers when the presence of overhead lines would interfere with traffic. The usual construction of a submarine cable calls for each conductor to be made of three strands of No. 24 B. & S. gauge copper wire tinned, rubber insulation being used. The conductors forming a pair are twisted together, the length of the twist not exceeding 6 inches. The pairs are bound together with cotton thread saturated in paraffine, and the whole is incased in a lead sheath of the usual construction. Over the lead sheath, steel wires of a diameter of .2 inch are wound helically. These steel wires constitute the armor, and are provided to protect the cable against mechanical injury. Over this armor is wound very tightly a layer of tarred oakum, to protect the wires from the action of the water. In Fig. 150 is shown the cross-section of an armored submarine cable, in which the conductors are shown at *a a' a,''* etc., with their rubber insulation. The paraffined cotton binding is shown at *b*, and the lead sheath at *c*. At *d d' d''*, etc., are seen the armor wires, with the marlin binding at *e*. This form of cable, owing to the use of rubber for insulation and to the fact that the armor wires surround the whole, has a very high static capacity, which is increased when the cable is laid, because of the presence of the water in such close proximity. The use of the stranded conductors is to give the cable increased flexibility, enabling it better to conform to the contour of the bottom upon which it is laid.

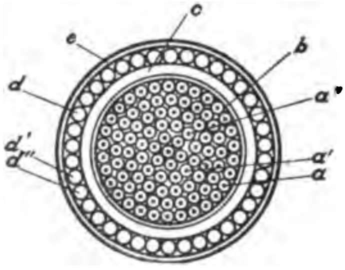


Fig. 150.

In order to reduce the capacity of the cable as much as possible, the Long Distance Company are using a submarine cable in which the insulation is of paper saturated with asphalt. The armor wires are replaced by a second lead sheath placed outside of the first one. This style of cable gives good satisfaction for short lengths, but is much more easily injured by mechanical shocks than the other described. For long spans — 200 feet and more — the armored cable is to be preferred.

In terminating rubber-insulated submarine cables it is not necessary to make a pot-head, as the nature of the insulation itself precludes the entrance of moisture. In terminating the asphalt-filled cable, the usual pot-head must be made.

TRANSPOSITION.

It is a well-known fact following from the laws of self-induction and mutual induction, that if two wires be placed parallel to each other, an alternating current flowing in one wire will induce similar and opposite currents in the other. These induced currents may be caused by the presence of the magnetic field set up around the first wire, or may be due to the electric stress set up between the two wires. The first is called **electro-magnetic induction, and** the second **electrostatic induction.** Electro-magnetic induction is illustrated in Fig. 151. Suppose that in the line *a b* an alternating current is flowing, and that the alternating magnetic field set up thereby is represented by the concentric circles. As these magnetic lines cut the telephone circuit *c* carrying the two receivers *e* and *d* an induced current will be set up in the telephone circuit, which either opposes or agrees in direction with that of the current flowing at that instant in the first circuit. This induced current will manifest itself by the presence of noise in the two receivers. As the current in the wire *a b* increases, the induced magnetic field, becoming therefore stronger, will cut across the wire *c*, and the induced current will be in the opposite direction to that which induces it. As the current in *a b* decreases, the induced field will contract towards the wire cutting the line *c* in the reverse direction, and inducing a current therein, which is in the same direction as that in the line *a b*.

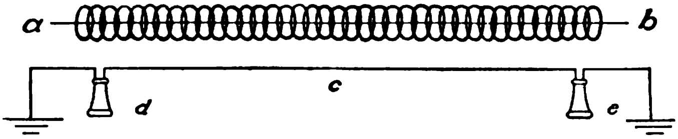


Fig. 151.

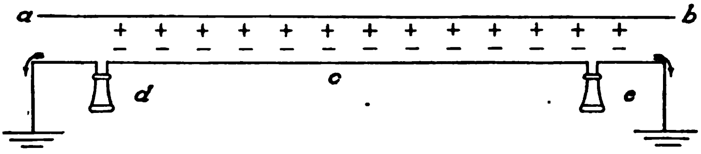


Fig. 152.

In Fig. 152 is illustrated the nature of electrostatic induction. Suppose the line *a b* again to be the disturbing wire carrying an alternating current. Under these conditions the medium around it will receive alternate positive and negative charges. Consider the instant when it receives a positive charge, as shown in the diagram. The medium surrounding the telephone wire will by static induction receive a negative charge; the positive charge, being repelled by that on the disturbing wire, will flow to ground in the direction indicated by the arrows. With each alternation in the disturbing current, the direction of flow of this repelled current is changed, with the resultant noise in the receiver. Such a disturbance would be produced by the proximity of electric light and power wires running parallel to the telephone lines. This kind of disturbance will be treated in greater detail later on. It will be evident that the same effect will also be produced by two telephone lines running parallel and in close proximity. In this case the effect of the induced currents would be not merely to produce noise, but to repeat on one line, more or less distinctly, the conversation carried on over the other. Such an effect is called **cross-talk.**

Mr. J. J. Carty, chief engineer of the New York Telephone Company, carried on a series of experiments to prove that cross-talk was not the result of electro-magnetic induction, but wholly due to electrostatic induction. In Fig. 153 is shown his method of experimentation. The line *a b*, one end *a* being open, had the other end grounded through the secondary winding of an induction coil. The primary winding was connected through a transmitter to a battery. A constantly vibrating tuning fork placed in front of the transmitter caused an alternating current to be induced in the line *a b*. Since one end of this line remained open, the only current that could flow was that necessary to charge the line up to the potential of the impressed E. M. F. Therefore the electro-magnetic induction was negligible. At the moment when a positive charge was held on the line *a b*, a negative charge was induced on the other line, the positive charge, as already explained, being driven to earth in the direction shown by the arrows. As the charge on the wire *a b* changes from positive to negative, that on the other line changes from negative to positive. the negative charge being released and driven to

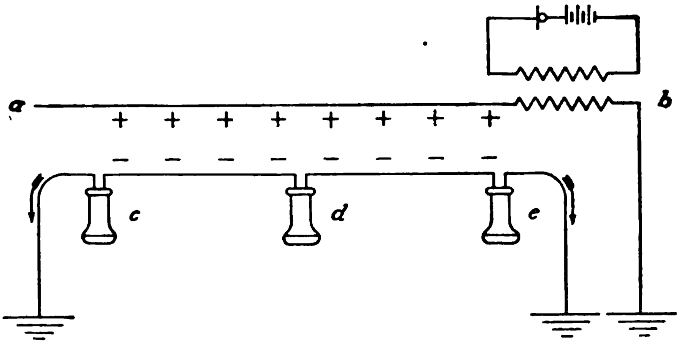


Fig. 153.

earth by the path already described, and its place being taken by the positive charge which flows up from the earth at both ends of the line. As a result the current flow in this line was either from the center toward both ends, or from both ends toward the center. The lines used by Mr. Carty were each 200 feet long, and separated from each other by $\frac{1}{8}$ inch. The nature and direction of current flow was proven by the fact that a receiver *d* placed in the center of the line gave perfect silence, while noise was heard in the other two. The proof was made still stronger by the fact that when the wire was opened at its center point noise was still heard in the two receivers *c* and *e*.

When the line between Boston and New York was built, and telephone communication first established between these two cities, it was found that cross-talk was very marked, and in some cases so serious as to interfere with conversation. It was this fact that started Mr. Carty on his series of experiments, with the results already given.

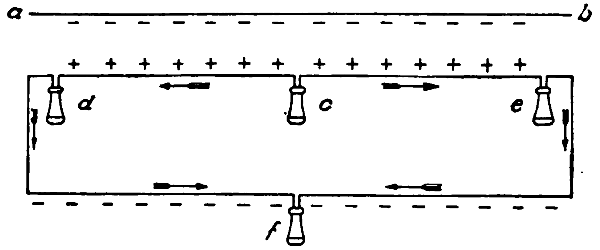


Fig. 154.

So far, grounded circuits only have been considered. If the telephone circuit is metallic, and the disturbing wire is placed so as to be at equal distances from the two conductors of the telephone circuit, no induced current will be produced in the latter, since, if the disturbing wire has a positive charge at any time, the surfaces of the two telephone conductors nearest to it will have a negative charge, while those most remote will have a positive. As the charge on the disturbing wire changes to negative, that on the adjacent surfaces will change to positive, while that on the remote surfaces will become negative. Since the telephone circuit is not grounded, it is obvious that the only way for this change to take place, is by the current flowing across the wire, which produces no noise.

When the two conductors of the telephone circuit are at unequal distances from the disturbing wire, a different condition prevails. This is shown in Fig. 154. At the instant that the disturbing wire receives a negative charge, a positive charge is induced on the adjacent surface of the nearest telephone conductor, the negative charge being repelled to the remote conductor, causing a flow of current away from the receiver *c* towards the receiver *f*, in the direction indicated by the arrow, with a resultant noise in the receivers *e* and *d*.

It will now be apparent that if two metallic telephone lines are placed side by side, the conductors of the circuits not being disposed symmetrically with respect to each other, an effect similar to that illustrated in Fig. 154 will be produced and cross-talk will result. This condition is overcome by transposing the conductors of one of the circuits at certain intervals as shown in Fig. 155, where *a a′* is one circuit and *b b′* the other. At *c* and *d* the position of the conductors of the latter circuit is reversed so that both are equally exposed to the effect of the circuit *a a′*. As a result, any disturbing influences coming from *a a′* are felt equally by both conductors of the circuit *b b′*, the induced current in one conductor balancing that in the other, with the result that no current flows. This is called **transposition,** and is resorted to on all open-wire lines to prevent cross-talk. Quite an elaborate scheme has been worked out for transposing the conductors on lines carrying several cross-arms. The scheme is shown in Fig. 156, and is described as follows:

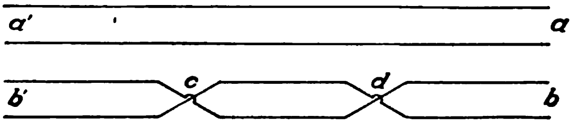


Fig. 155.

Starting from the first pole, a distance of 1,300 feet is measured off, and the pole nearest to this point is marked *A*. From the pole A, a second 1,300 feet is measured off, and the pole at this point marked B. Another 1,300 feet is measured off, and the pole at this point marked C. The distance is again measured, and the corresponding pole marked B. This process is continued, the transposition poles being marked as shown by the capital letters in the diagram. Referring to the top arm, at the A poles the wires on pins 1 and 2, 3 and 4, 9 and 10, are transposed. At the B poles the wires on pins 7 and 8 are transposed; while at the C poles those on pins 3 and 4, 5 and 6 are transposed. Referring to the second arm, on the A poles the wires on pins 15 and 16, 17 and 18 are transposed; while on the B poles the wires on pins 13 and 14 are transposed. On the C poles the transpositions are made in the wires on pins 11 and 12, 17 and 18, 19 and 20.

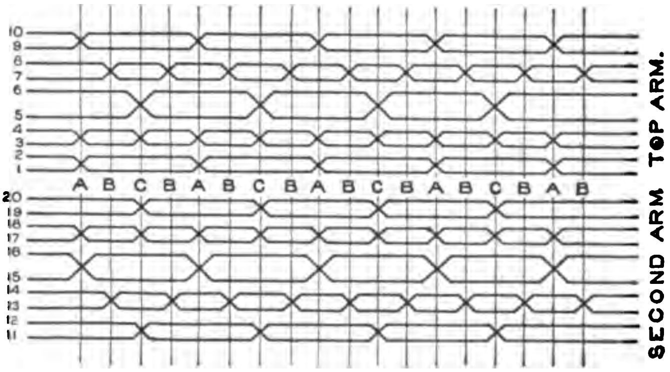


Fig. 156.

When a third arm is placed, the wires on this are transposed the same as those on the first; and should a fourth arm be used its wires would be transposed similarly to those on the second. The method of cutting in the transpositions is shown in Fig. 157 and Fig. 158. The former is applicable to the case where the insulators are on the same side of the pole, while the latter is used when the pole lies between the two insulators. Referring to Fig. 157, the wire *a*, being one conductor of the pair, is brought around the top glass of a transposition insulator *x*, and secured by a McIntire sleeve *b*. The free end is run through a second sleeve *c*. The wire *a'*, being that to which *a* is to be transposed, is cut through the sleeve *d'*, the short end being wound around the upper glass of the transposition insulator *x'*, brought through the sleeve *b'*, and ended in the sleeve *c*. The wire *a'*, being the mate of *a*, is brought round the lower glass of the transposition insulator *x'*, passed through the sleeve *b'*, the free end being terminated in the sleeve *c.'* The wire *a*, being that to which *a'* is to be transposed, is cut through the sleeve *d*, the short end being wound around the lower glass of the transposition insulator *x*, passed through the sleeve *b*, and terminated in the sleeve *c'*.

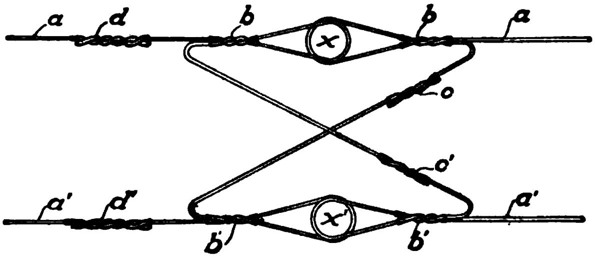


Fig. 157.

It will be observed that the transposing wires run between the two upper and the two lower glasses respectively, so that there is no chance for them to come in contact. In Fig. 158 the pole is represented at P, and to avoid it the transposing wires are carried around the insulators before crossing over. Otherwise the method is the same as that shown in Fig. 157. This is called **a transposition.**

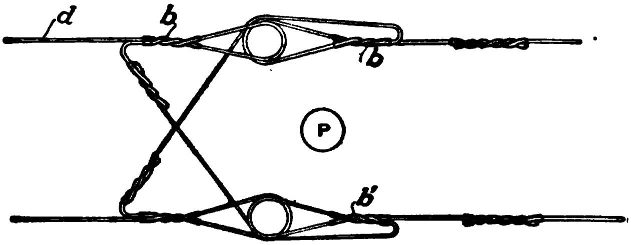


Fig. 158.

TERMINAL POINTS.

The terminal points of a line, as the name indicates, are the points in which the line terminates. In the case of trunk lines the terminal points are the two exchanges that the lines connect. In the case of subscriber lines, one terminal is the exchange, and the other the subscriber telephone. The term is also used to denote the point where a certain class of line ends, the circuits being continued by another class of line — for example, the point where a cable line is connected to an open-wire line, or where a submarine cable line ends.

The method of terminating lines in an exchange, consists, in the case of cables, in making a pot-head in the manner already described, and connecting the conductors of the pot-head cable to a piece of apparatus called the "main distributing frame." This subject will be described in detail under the heading of "Telephone Exchanges," where it properly belongs. Where the line approaching the exchange is of the open-wire type, it is connected to a bridle cable at the point nearest the exchange, the bridle cable being carried inside. The manner of terminating open-wire lines outside of an exchange consists in simply dead-ending them on the insulators in the way already described, terminal cross-arms being used.

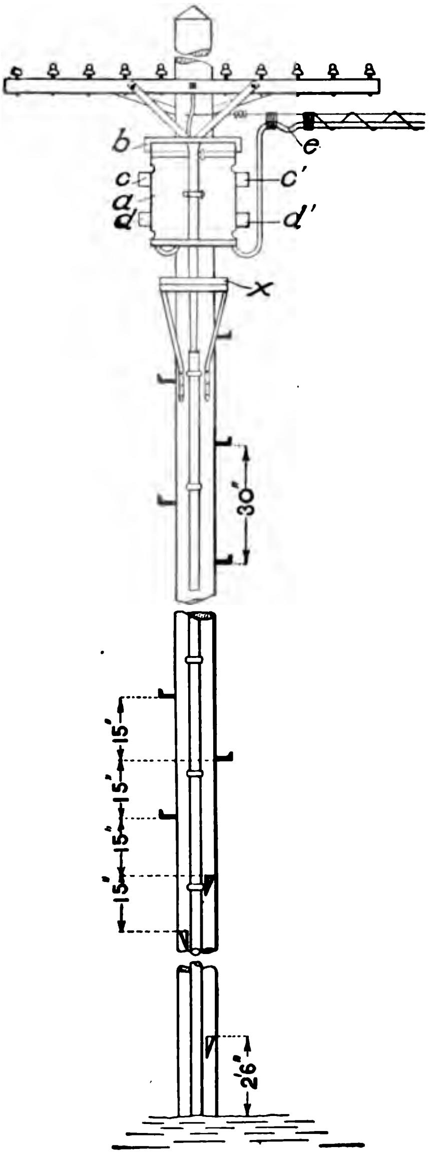


Fig. 159.

The terminating of a cable, whether aërial, underground, or submarine, is a more elaborate affair and needs to be done with great care. In this case a piece of apparatus called a **cable box** is used. A cable box is a box made of pine, strongly put together and of sufficient size to enable all the conductors in the cable to be arranged in order and permanently terminated within the box. It should be perfectly water-tight, and the door should be so constructed as to prevent the rain from entering on being opened in wet weather. In Fig. 159 is shown at *a*, a cable box mounted on a pole. The roof *b* is made to slant towards the pole, and projects sufficiently over the side and at the front to throw off water. The arrangement of the apparatus inside of a cable box is shown in Fig. 160. The underground cable or submarine cable, as the case may be, is brought up through a hole in the center of the box, the pot-head being shown at *a* in the figure. The pot-head cable is fanned out, or **formed,** in the manner shown, and its conductors are attached to the binding-posts arranged on two strips *d* and *d'*. At *e*, *e'*, *h*, and *h'* are four strips of maple cleats with holes bored through them horizontally, as shown by the dotted lines. These cleats and the strips of binding-posts are firmly screwed to the back of the cable box. At the left-hand side of the box, at *b*, is shown a bridle cable, which comes down from the cross-arm, where it takes the open wires. It is formed as shown, and is connected to the strip of binding-posts *i'*. At the right-hand side of the box, at *c*, is seen an aërial lead cable, which comes down from above, and which, being formed, is connected to the binding-posts on the strip *i*. Referring to the two strips *d* and *d'*, and beginning at the top of the latter, the binding-posts are numbered downward in series from 1. For example, the top post is No. 1, the second No. 2, the third No. 3, etc. Assuming that there are 50 binding-posts on each strip, the bottom one on strip *d'* would be No. 50. The post at the top of strip *d* would be No. 51, and the bottom one on this strip No. 100. In connecting up the cable conductors to these posts, the first pair is placed on posts Nos. 1 and 2, the second pair on posts Nos. 3 and 4, and so on. The binding-posts on the

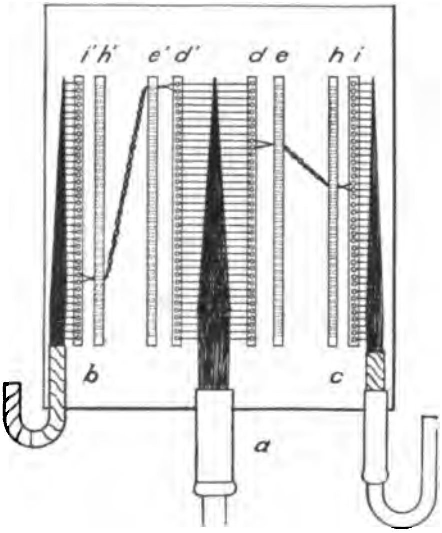


Fig. 160.

strips *i* and *i'* are also numbered from the top downward in series; that at the top of strip *i* is No. 1, as is also that at the top of strip *i'*. The wires in these two cables are connected in pairs exactly similar to those of the underground type. The pairs in the underground cable are connected to those in the bridle and aërial lead cables by what is known as **cross-connecting.** By means of a piece of twisted pair wire No. 19 B. & S. gauge, rubber-insulated, and braid-covered, the proper connections can be made. One end of each wire of the pair is connected to the proper binding-post of the underground cable, the other ends being connected to the proper binding posts of the bridle or the aërial lead cable, as the case may be. The cross-connecting wire is passed through the holes in the cleats as shown. Should it be necessary to connect a pair of the underground, terminating on the left-hand strip of binding-posts, with a pair in the aërial lead cable, the cross-connecting wire, after being passed through the hole in the cleat *e'*, is carried to the top of the box and is passed through two japanned iron rings to the right-hand side of the box, to the proper point. The same practice would be resorted to if it were desired to connect a pair on the strip *d* with one on the strip *i'*.

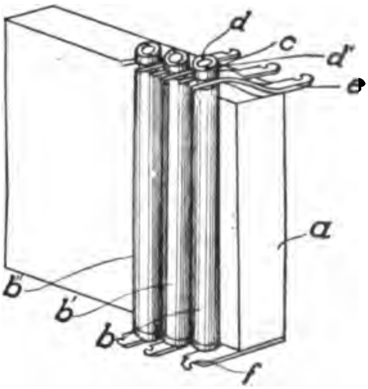


Fig. 161.

Whenever an aërial lead cable runs for any considerable length, say 200 feet or over, the conductors should be protected at the cable box by fuses suitably mounted. A strip of these arresters is shown in Fig. 161. They are mounted in the box and take the place of the binding-posts. The strip consists of a block of wood *a*, on the top of which are securely fastened brass lugs, one of these being shown at *e*. These lugs are bent as shown, and are slotted at one end and nicked at the other. To the bottom of the block are fastened a second row of brass lugs *f*, etc., through the center of which a hole is drilled and tapped. The tubular fuses are shown at *b b' b''*, etc. They consist of a fiber tube, to the bottom of which is fastened a brass cap with a projecting screw that fits into the hole in the bottom lug. The top of the tube is equipped with a cap and hollow screw, over which fits a ring-nut *c*. This nut is slotted at *d d'* so that it can be set with a screw-driver. The fuse, which has a capacity of 7 amperes, is soldered to the bottom cap, passed up through the center of the tube, and soldered to the edge of the hollow nut. The conductors in the cable to be protected are soldered to the bottom lugs, while the cross-connecting wire is soldered to those at the top.

Returning again to Fig. 159, it will be seen that the cable box is mounted by fastening two boards, the ends of which are shown at *c c'* and *d d'*, to the back of the box, and bolting these with cross-arm bolts to the pole. The cable-box door is shown closed, and should always be secured with a padlock. At *x* is shown a pole seat, which is placed on the pole to afford a seat for the lineman while working. The method of bringing a lead aërial cable into the box is also shown; and it will be seen that the cable is given a bend at *e*, called a **drip loop,** which prevents water from following the cable down to the box. The underground cable is brought from the nearest manhole to the bottom of the pole, through an iron pipe laid in the earth. The pipe is bent and runs up the side of the pole to the height of 15 feet. From this point to the cable box, the cable is protected with a covering of sheet iron.

TEST POINTS.

Test points are placed here and there in a long line, to afford means of opening the line for the purpose of testing. Such points are necessary on toll trunks only. In many cases, toll trunks pass through several exchanges before reaching their destination, and under these conditions test points are not usually needed. The necessary number of test points on a line has never been definitely figured out. The Long Distance Telephone Company formerly placed test points at about every 50 miles. More recently, however, this distance has been reduced to 30 miles. The point to be considered in locating test points is the amount of ground that the lineman can cover in clearing trouble. In flat country traversed by good roads, the lineman can take care of a longer stretch of line than in rough country where movement from point to point is not so easy. He is at still better advantage at points where the line runs parallel to a railroad track, for in this case he can make use of the train service in clearing trouble.

The test point is located in a convenient building, which usually becomes the lineman's home. The method adopted for bringing the wires into this building is the same as that described for connecting a bridle cable to an open-wire line. The other end of the cable, instead of going into the cable box, is cut into the building. In Fig. 162 is shown the standard form for cutting the conductors of the bridle cable onto the open wires. The line wires at this pole are dead-ended both ways as shown, transposition insulators being used. The free end of the line wire, after being passed through the McIntire sleeve, is bent down at right angles, and the conductor of the bridle cable is soldered to it. These conductors are brought down beneath the cross-arm, and are passed through wooden cleats to prevent the insulation from touching the creosoted arms, as it has been found that creosote has a deteriorating effect upon the insulating material.

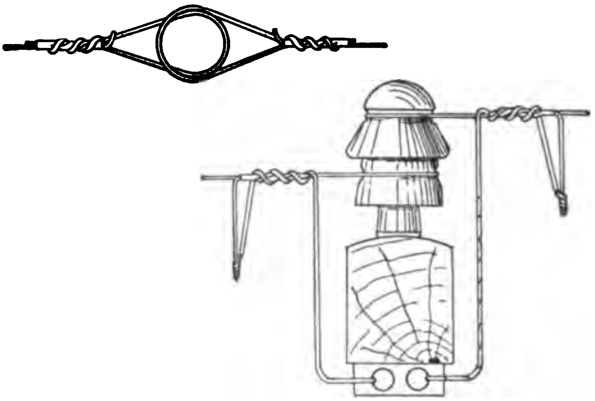


Fig. 162.

In Fig. 163 is shown the method of wiring a test pole. It will be seen that the wires are dead-ended both ways, the short ends being brought over the top of the insulator and placed in a clip *a*, a firm connection being made by means of the thumb-screw *b*. In making the test, the lineman opens the line by removing the clip, and is thus enabled to connect himself with either end of the line independently.

The method of wiring up a test house is shown in Fig. 164, in which *a b*, *a′ b′* represent the top and bottom glasses respectively of two transposition insulators, the method of cutting in the bridle cable at the pole having been already shown. At *c c′ c″ c‴* are shown four pieces of apparatus called **jacks.** Each one consists of a brass ring *e*, *e′*, etc., a German silver spring 1, 2, etc., and a contact point shown by the arrow. When a properly shaped plug is introduced into the ring *e*, the plug is held firmly, and its end makes contact with the end of the spring 1, pushing it to one side and in so doing breaking contact with the contact point When the jacks are without plugs, the two conductors from *a a′*, being wired to the two springs 1 and 2 of the two jacks *c* and *c′*, form a connection through the arrow points to the springs 3 and 4 of the jacks c″ and c‴, thence passing out to the line wires at the transposition glasses *b* and *b′*. By introducing a plug into each of the jacks *e* and *e′*, the line is opened towards the west, and communication is established with the east. If on the other hand a plug is introduced into each of the jacks *e″* and *e‴*, the line is opened towards the east and communication is established with the west.

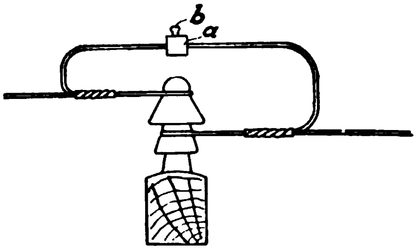


Fig. 163.

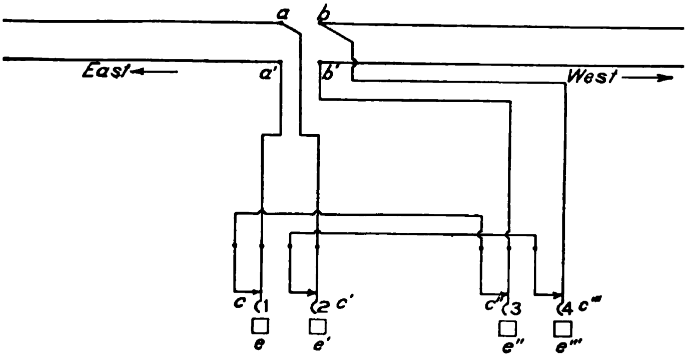


Fig. 164.

DISTRIBUTING POINTS.

As the name indicates, these are points where the line wires are distributed to the subscribers' telephones. The simplest method of distribution is from an open-wire line by means of twisted-pair wire. This case is illustrated in Fig. 165, which will be recognized as exactly similar to that of cutting in for a test station. The line is dead-ended in the usual manner, the twisted-pair wire being brought down to the bottom of the arm and passed through cleats to preserve the insulation, and springing away from the cross-arm at the point nearest to the location of the subscriber's station.

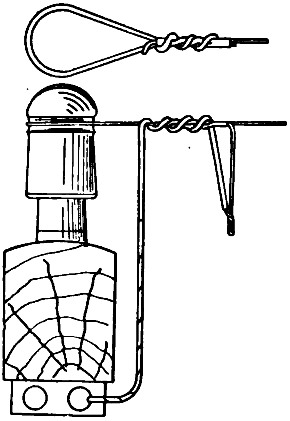


Fig. 165.

In residential districts where the running of overhead lines must be restricted as far as possible, it is often most convenient to run the underground cable into the rear yard of some house, in which permission has been granted to erect a distributing pole. The cable is carried to the top of this pole and terminated in a pot head, the conductors being fastened to binding posts. One such pole is shown in Fig. 166. The pole is of the box-girder type, made of steel, and equipped with steps for the use of the lineman in climbing. At the top is a flat ring, on which are mounted the binding-posts. On the bottom of this ring are mounted porcelain insulating knobs, shown at *a* etc. in the illustration, and to which are securely fastened the distributing wires. The pot head is covered with a sheet-iron hood for protection against the weather. Distributing wires will be seen at *b*. In Fig. 167 is shown a rather more elaborate type of distributing hood. It consists of a sheet-iron cylindrical box *a* surmounted by a hood *b*. This box contains the

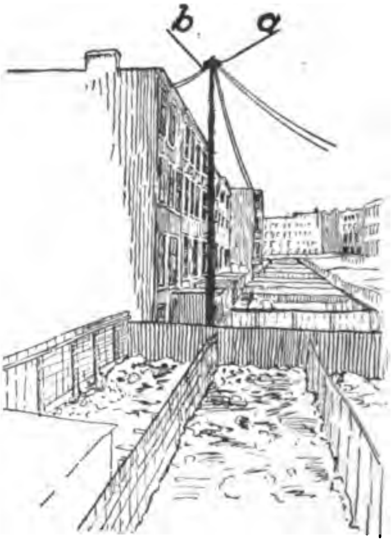


Fig. 166.

binding-posts and protecting fuses at which the cable is terminated. The cable can be seen fastened against the pole by an iron pipe *c*, with the pot head at *d*. The flat distributing ring can be plainly seen, and is equipped with small hard-rubber-covered rings, one of which is shown at *e*, which are used to secure the distributing wires. The distributing wires also can be plainly seen. They are No. 14 B. & S. gauge, tinned, covered with rubber insulation and heavy braid. The copper is hard-drawn, and has a breaking weight of 200 lbs. The conductors forming a pair are twisted together, the length of the twist not exceeding 3 inches. The hood is shown mounted on a wooden pole, but it can also be used on an iron pole.

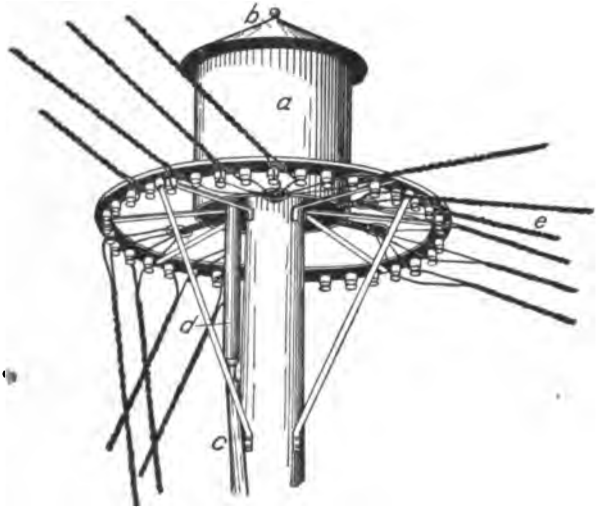


Fig. 167.

The New York Telephone Company has developed a system of distribution called the "block" system, which is used exclusively in the down-town districts. The features of this system are as follows:

The underground cable from the exchange terminates in the cellar of one of the buildings in a block, in the regulation cable box, Fig. 159. In this box terminate also one or two other cables, called **block cables**, which have their other terminals in the cellars of the various buildings in the block. These cables are usually bridging cables. From each of the terminals of the block cables, run house cables — one cable for each building — which have terminals on each floor. If a subscriber is to be given service anywhere within this block, all that is necessary is to make the proper cross-connection between the underground cable and the block cable, and between the block-cable terminal and the house cable. The only wire that need be run is that from the telephone instrument to the house-cable terminal on the same floor. The wire used for this purpose is called **house wire.** It is No. 19 B. & S. gauge tinned wire, soft-drawn, and covered with rubber insulation $\frac{1}{8}$ inch in thickness. Over the insulation is woven a cotton braid, which is colored to imitate oak, mahogany, or cherry finish. The conductors are twisted together, the length of a twist not exceeding 2 inches.

LINEMEN'S TOOLS.

Climbers. A word should be said here about the nature of the tools used by the lineman, and the method of using them. The first requisite in the lineman's kit of tools is the climbing irons, or **spurs,** as they are called. These are worn to assist in climbing up and down the pole. They are made in two forms as shown in Figs. 168 and 169. Both types are made of wrought iron, with a steel spur welded on.

In Fig. 168 is shown what is termed the "Western" spur from the fact that it is used more in that part of the United States than in the East. It consists of a wrought iron strip *a*, the upper end being shaped into an "eye" *c*, while the other end is bent at right angles to pass under the instep, curving upward slightly to give the foot a firm hold. At the extremity is the wrought steel spur *b*, which bends downward—so that it can be jabbed into the pole by an inward and downward motion of the foot. The device is held in place by a strip passing through its "eye," and around the upper part of the thigh of the climber. The strip *a* is on the outside of the leg when in place.

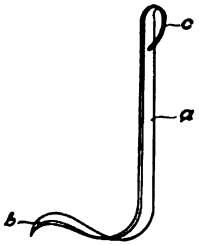


Fig. 168.

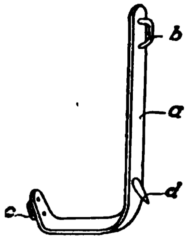


Fig. 169.

In the Eastern type shown in Fig. 169 the strip is equipped with an "eye" at the upper and also at the lower end, the former being shown at *b* and the latter at *c*. The spur *d* is welded to the lower part of the strip. When in place the strap *a* is on the inside of the leg, and is held in place by two leather straps, one passing through the eye *c* and the other passing through the eye *b*.

One of these types is about as good as the other, the Western being somewhat simpler in construction and easier of adjustment.

In climbing, the pole is grasped with the fingers and lower part of the palms of the hand, and the spurs are jabbed into the side of the pole with a downward thrust. Care should be taken not to "hug" the pole but to hold on at arm's length. To be a good climber requires a cool head and strong muscles, and it is well for a beginner to practice at moderate heights — say 15 feet in order to accustom himself to the work before he attempts to climb higher.

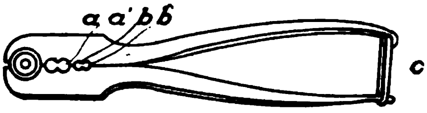


Fig. 170

Pliers and Wrenches. In addition to the ordinary pliers used, the lineman carries a wrench, shown in Fig. 170. It is made in the form of ordinary 9-inch pliers, but is equipped with two sets of circular jaws shown at *a a'* and *b b'*, the former being for No. 8 wire and the latter for No. 12. The wrench is held closed by a lock *c*, which holds the two handles together. This wrench is used to twist McIntire sleeve joints. Two such wrenches are used together, one being clasped over one end of the sleeve and held rigid, while the other is clasped over the opposite end of the sleeve and rotated until the requisite number of twists have been made.

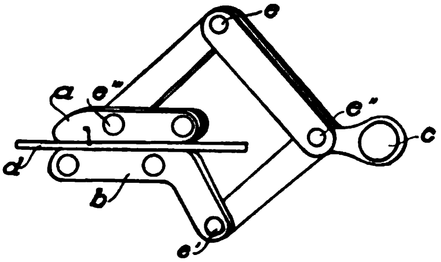


Fig. 171.

Come Alongs. This term is used to denote the mechanism used to pull up open wires to the proper tension. The device is shown in Fig. 171. It consists of a set of jaws *a* and *b*, which are pivoted to two links at *e'''* and *e'* respectively. These links are strapped together by pivoted joints at *e* and *e''*, so that by pulling on the "eye" *c* the jaws are brought together, always maintaining a parallel position. The wire to be pulled up is placed between the two jaws as shown at *d*, the whole being drawn up by a rope attached to *c*.

TELEPHONE EXCHANGES

The subject to be studied now is the method employed to so terminate telephone lines, that the proper connection can be made when one subscriber wishes to converse with another. This subject naturally divides itself under two heads: first, the terminating lines as they enter the exchange building; and second, the arrangement of these terminals, so that the proper connections can be made. To accomplish the desired results, two pieces of apparatus are necessary: that used in properly terminating the lines is called *The Distributing Board.* That used in properly arranging the terminals so that connections may be made, is called *The Switchboard.* Auxiliary apparatus is also needed, but it should be remembered, that the two principal pieces of apparatus in a telephone exchange are the distributing board, and the switchboard. In dealing with the subject of telephone exchanges, the terminating of the lines will be considered first, and later the distributing board will be described in detail.

The design and use of a distributing board is based upon the following principles. All wires entering an exchange, whether of the open-wire or cable type, must be permanently connected to fixed terminals. All wires running between the distributing board and the switchboard, must be permanently connected at the former end to fixed terminals. These two sets of terminals must be so arranged with respect to one another as to be really connected together, or disconnected according to the needs of the case.

By this means, the two systems of wiring — that entering the exchange from without, and that between the switchboard and the distributing board — are entirely independent of one another, and either one can be changed without necessitating a change in the other.

Numbering. All conductors entering an exchange are numbered according to some system, and the numbers are placed opposite the terminals on the distributing board. The conductors on an open-wire line, are numbered to correspond with the pins on which they are placed. The pins are numbered in the following manner: standing with the back to the exchange, and facing the direction in which the pole line runs, the left-hand pin on the top arm is No. 1; that to the right of it, No. 2; and so on till the right-hand pin on the top arm is reached, which is No. 10. The left-hand pin on the second arm is No. 11; and the right-hand pin on the same arm, No. 20, and so on to the right-hand pin on the bottom arm. This system is maintained whether or not wires are attached to the pins in consecutive order. For example, suppose that pins Nos. 1, 2, 3 and 4 have wires attached and that the rest of the pins are vacant to pin No. 15, the wire on this pin would still be No. 15.

All cables entering an exchange are numbered consecutively. In cities having more than one exchange, cables entering one exchange are distinguished from those entering another by a different hundred. For example, the cables entering the Broad St. Exchange in New York are numbered from 1 to 99; those entering the Cortlandt St. Exchange in the same city are numbered from 100 to 199. Those entering the John St. Exchange are numbered from 200 to 299, etc. The conductors in the cable are numbered from 1 up, each one taking its number from that of the binding post in the cable box to which it is attached. The wires running to the switchboard are numbered in an altogether different manner, which will be explained.

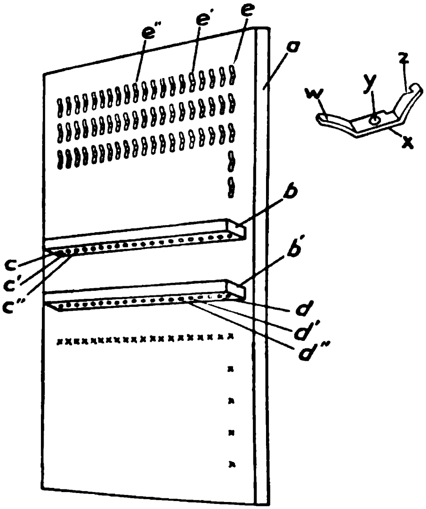


Fig. 172.

Main Distributing Board. The style of the distributing board varies with the size of the exchange, and also with the ideas of the designer. For small exchanges, in which 100 or 200 lines terminate, it is a very simple affair. In Fig. 172 is shown one type of this piece of apparatus used with small exchanges. It consists of a board *a* of maple. The size of this board depends upon the number of lines to be handled. For 100-line capacity it is about 3 feet by 2 feet, while for 200 lines it is about 4 feet by

3 feet. Two maple cleats *b* and *b'* are fastened to the board, and have holes bored in them, shown at *c*, *c'*, *c''*, etc., and *d*, *d'*, *d''*, etc. These holes are for the accommodation of the cross-connecting wires. The cleats are similar to those used in cable boxes which have already been described. Fastened to the face of the board by small screws *e*, *e'*, *e''*, etc., are brass clips, one of which is shown in detail at *x*. The hole through which the screw passes is shown at *y*. There is a nick in each end of the lug for the wire; one of them being shown at *z*.

The lugs in each group correspond in number to the number of conductors handled; the one shown in Fig. 172 having a capacity of 50 lines.

The lines coming in from the outside, are brought to the back of the board and soldered to the lugs, being passed through holes for the purpose. The conductors from the switchboard are treated in a similar manner and soldered to the bottom row. The cross-connecting wire is run on the face of the board, and is passed through the proper holes in the cleats, and soldered to the opposite side of the lug. Referring to the detail, the outside wire would be soldered at *z*, and the swichboard wire at *w*. For cross-connecting purposes, the wire is the same as that used in cable boxes.

This form of distributing board is very compact and admits of the connection being established between any switchboard wire and any pair of wires coming in from outside.

There are certain essential features which this form of board does not possess, and which are absolutely necessary in a distributing board in an exchange of any considerable size. First, this arrangement of terminals is not the most economical as regards space. Second, it does not make provision for protecting the switchboard from lightning or foreign currents. Third, it is very difficult to get at the inner lugs for soldering wires or breaking connections. Fourth, it does not afford an easy way of opening a line for testing. While it is not essential to have the high-potential protecting apparatus mounted on the distributing board, and while many excellent boards have been designed without this feature, it is absolutely necessary that a distributing board for a large exchange should possess the other features.

Hibbard Distributing Board. In Fig. 173 is shown a distributing board designed by Mr. Hibbard, which, although now out-of-date, was formerly extensively used. It consists of an iron rack upon one side of which are fastened wooden horizontal strips shown at a, a', etc. On the opposite side, the same kind of strips are fastened vertically as shown at e, e', e'', etc. Down the center of the rack run horizontal iron rails d, d', d'' etc. to which are fastened rings. The wooden strips have holes bored through the center, and on opposite sides are mounted brass punchings as shown in the detail, where the hole is at x, and the punchings at y, y'. Two of these punchings are shown at c and c'.

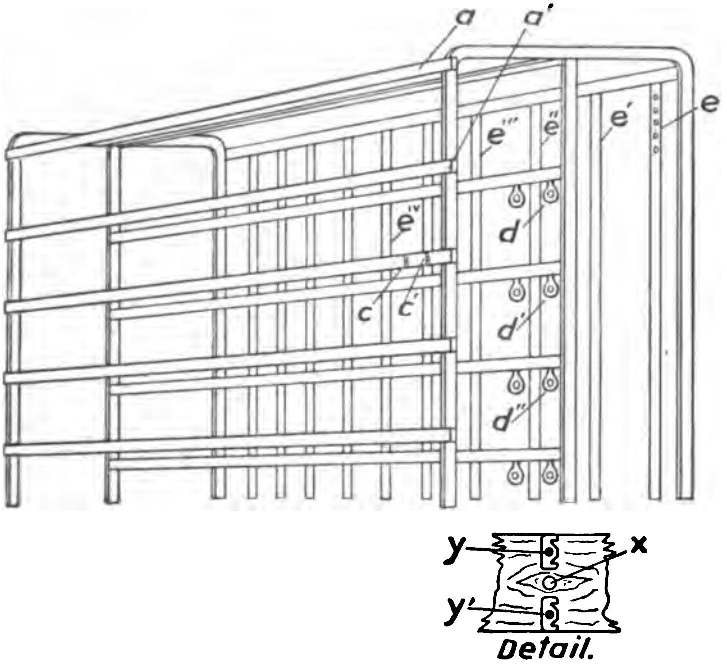


Fig. 173.

The method of using this rack is as follows: The cables from outside are formed upon the inside of the vertical strips, the conductors being passed through the holes. Pairs are connected to the lugs on the opposite sides of a hole. The conductors from the switchboard are formed upon the inner side of the horizontal rails, and connected in the same manner as described for the cable conductors. The cross-connecting wires are brought over the edges of the rail and soldered to the outside ends of the lugs. The cross-connecting wires are passed from the horizontal rail diagonally to the ring opposite the proper vertical strip, and thence through the ring to the proper lug. With this form of distributing board, the cable conductors are soldered to the lugs on the horizontal rails, while the switchboard wires are soldered to those on the vertical rails.

As has already been stated, this form of distributing board does not provide for the proper protection of the wires, so that additional facilities for furnishing protection must be at hand. The standard method of accomplishing this is to terminate the cable in what is known as a *cable head* which contains the desired protecting apparatus. One form of cable head is shown in Fig. 174, where *a* represents a cast-iron box, equipped at the back with lugs *b*, *b′*, *b″*, *b‴*, for fastening it securely to some suitable support. Over the front of the box fits a lid *c*, which, by means of a rubber gasket *x*, forms an air-tight cover. It is held in place by means of screws, *d*, *d′*, *d″*, etc. which fit into holes drilled and tapped into the edge of the box. Projecting from the bottom of the box, and secured to it by means of a lock-nut, is a brass sleeve *e*, to which, by means of a wiped joint, the sleeve of the sheath is attached. Projecting through the sides of the box, as shown at *f*, *f′*, *f″*, etc. are the connectors. They consist of hollow tubes of fiber held in place by lock-nuts. At the inner end of each is a binding post for attaching the cable conductors, while at the outer end is a larger one for attaching the cross-connecting wire. Running through the fiber tube and attached to both binding posts is a fuse, for protection against an abnormally large current.

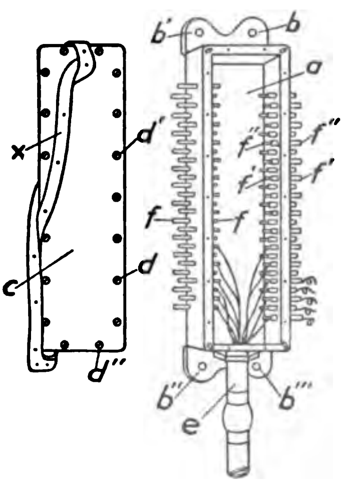


Fig. 174.

When a cable terminates in a cable head, it is not necessary to make use of a pot head; it is sufficient to wipe the sheath to the brass sleeve as already explained. The cross-connecting wire running from these terminals is soldered to the lugs on the horizontal rails of the distributing board. After the cable conductors have been properly fastened to the binding posts, hot paraffine is poured into the cable head several times, and while the inside is still hot, the lid is securely fastened.

The numbering of the binding posts begins on the left-hand side of the box at the top. The top front binding post is No. 1; that slightly lower and to the rear of the box is No. 2; that directly under No. 1 is No. 3, etc. This system is continued on the opposite side of the box beginning at the top and ending at the bottom.

The disadvantages of this method of terminating a cable are the extra cost of the box, and the extra run of cross-connecting wire from the cable terminal to the distributing board. While the fuse is a suitable protection against abnormal currents, it is not sufficient protection against the damage due to a sudden charging of the line with a high potential as in the case of thunder storms.

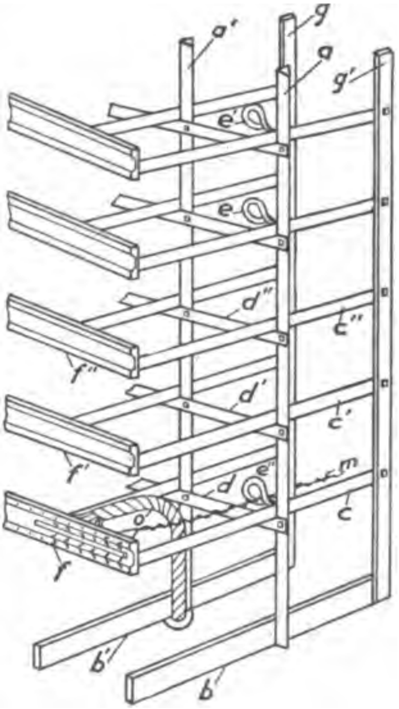


Fig. 175.

Ford-Lenfest Distributing Board. To do away with the cable terminal, and to place the necessary protecting apparatus in the most convenient place the form of distributing board shown in Fig. 175 was devised. It consists of a series of vertical iron beams of which two are shown at *a* and *a'*. They are held securely together by flat iron bars *d*, *d'*, *d''*, etc. These horizontal bars are fastened to the angles by bolts. Running at right angles to *d*, *d'*, *d''*, etc. is a second set of flat iron bars *c*, *c'*, and *c''*, etc., which are bolted to the verticals, and which carry at one end a heavy, vertical iron strip *g*, *g*′, and at the other end, wooden channel pieces *f*, *f*′, *f*″, etc. These channel pieces, which are of maple, carry a series of brass lugs arranged in groups, each group taking up the space between two consecutive horizontal supports. Each group consists of 20 pairs of lugs.

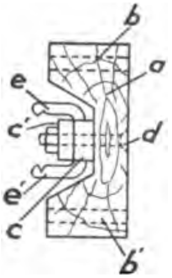


Fig. 176.

The end view of one of these channel pieces is shown at *a* in Fig. 176. Mounted in the channel is a hard-rubber strip *c*, into which slots are cut for the accommodation of the lugs. These slots are of sufficient depth to allow the top of the lug to project about $\frac{1}{50}$ of an inch. On top of this is placed a second hard-rubber strip *c*′ which is securely bolted to the first one and to the maple strip by brass bolts, one of which is shown at *d*. The lugs are made with two ears, *e* and *e*′. Two holes *b* and *b*′ are bored through the channel piece opposite each pair of lugs for the accommodation of the wires. To the vertical iron strips *g* and *g*′, Fig. 175, are attached the protecting device to be described directly. Rings *e*, *e*′, etc., Fig. 175, are fastened to the horizontal braces at each section for the accommodation of the cross-connecting wires.

This form of main distributing frame is used exclusively by the Bell Companies, and is made in two forms, known as the 4a and 4b frame. In the 4a frame, the cable conductors are attached to the lugs on the horizontal channel pieces; while in the 4b frame, the cable conductors are connected to the protecting apparatus on the vertical side. In the 4a frame, the switchboard wires are attached. to the protecting apparatus, while in the 4b frame, they are attached to the lugs on the horizontal side. In Fig. 175, a cable is shown at *o*, coming up through a hole in the floor. It is fanned out at the rear of the strip, and its conductors are brought through the bottom row of holes and soldered to the lugs. A cross-connecting wire is shown at *m*; it is soldered to the upper ears of the lugs, and brought through the ring *e*″ to the vertical side.

The only difference in the make-up of the 4a and 4b frames lies in the style of protecting device. The 4a protection is shown in Fig. 177. At *a* is shown in cross-section the iron strip *g*′ in Fig. 175. Mounted on this strip is the protection which consists for each line of the following apparatus: On two hard-rubber blocks *c c'* are placed two German-silver springs *d d'*, with the ends bent up into lugs as shown. The opposite ends are slightly bent, one rests on the carbon block *g*, and the other on the carbon block *g'*. Firmly attached to each spring by rivets is a flexible strip of German silver, one of which is shown at *e*, and the other at *e'*. Resting on the two hard-rubber blocks *r* and *r'* are the two springs *i* and *i'* shaped as shown. Fitting into a hole drilled through *r*, *c*, *a*, *c'* and *r'*, are two hard-rubber sleeves *n* and *m*, the latter being provided with a shoulder which rests against the spring *i*. Through the center of these tubes passes a brass bolt *l*. It is held in place by a nut *p* resting on the lug *o* and one at the opposite end resting against the end of the short, hard-rubber sleeve *q*. In this way the lug *o* is in electrical contact through the bolt *l* and the nut *p*, with the spring *d'* while the three remaining springs are insulated from one another. Fastened to the end of *a* is a German-silver strip *f*, against which rest the two carbon blocks *h* and *h'*, which in turn rest against *g* and *g'* respectively. The spaces between *g* and *h*, and *g'* and *h'* are filled with a thin sheet of mica.

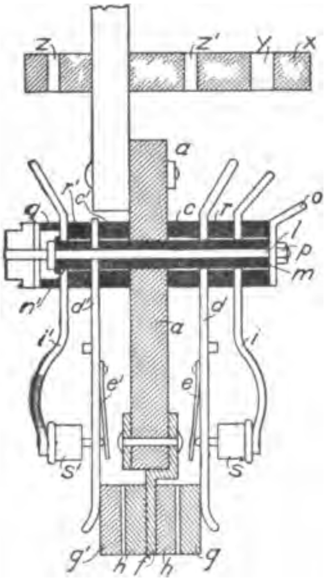


Fig. 177.

At *s* and *s'* are shown two pieces of apparatus called heat coils, shown in detail in Fig. 178. A heat coil consists of a fiber shell *a*, with a brass pin *c* passing through its center; soldered to this pin is a brass sleeve *d* so placed that there is an interval of about $\frac{1}{16}$ inch between its upper end and the top of the fiber shell. A coil of very fine wire, insulated with silk and cotton covering, is wound around this sleeve, one end being soldered to the sleeve, and the other to a brass plate placed on top of the shell. At *o* is shown a small fiber projection. Returning to Fig. 177; the heat coil is so placed that the fiber projection *o* fits into a slot in the spring *i* or *i'* and the pin *c* passing through a hole in *d* or *d'* rests on the German-silver strip *e* or *e'* as the case may be. The sleeve *d*, Fig. 178, rests on the edges of the hole and with the tension of the outer springs holds the heat coil in place. Starting from the lug *o*, Fig. 177, a circuit is formed through the brass bolt *l* to the spring *d'*, and thence to the sleeve of the heat coil *s'*. Through the winding of this coil it passes to the brass cap which rests against the spring *i'*, and thence to the lug at its end. Starting from the spring *d*, a circuit is made through the heat coil to the spring *i*, and thence to the lug *i'*. The cross-connecting wire, coming from the lugs at the horizontal side of the frame to which the underground conductors are also attached, is connected to the lugs *o* and *d*, while the switchboard wire is connected to the lugs *i* and *i'*.

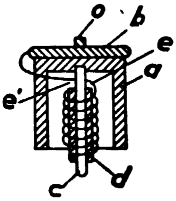


Fig. 178.

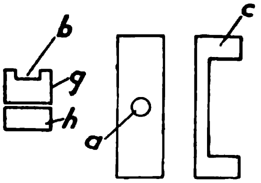


Fig. 179.

The carbon plates are shown in detail in Fig. 179. It will be seen from the end view that the upper plate *g* is slotted at *b*, so that the springs *d* or *d'* will hold it securely and not allow it to fall out of place. The lower carbon has a depression *a* in its upper surface which is filled with solder, care being taken to have the surface of the solder flush with that of the carbon. The mica separating the carbons is shown at *c*. It is about $\frac{1}{64}$ inch in thickness.

The action of the arrester is as follows: A high potential coming in on the line, as for example a charge of lightning, would pass over the springs *d* and *d'*, called the ground springs, and reaching the carbons *g* and *g'* would arc across the spaces between them and the other carbons *h* and *h'*, through the gap in the micas. This arc would melt the fuse *a*, Fig. 179, forming a permanent connection between the two carbons. The iron strip *a*, Fig. 177, being permanently grounded, a path is afforded directly to earth, thus saving the exchange wiring and apparatus from destruction. When the discharge has taken place all that is necessary is to replace the carbon plates by new ones, and blow away whatever carbon dust may have accumulated.

Should an abnormal current come in on the line of a potential not sufficient to arc between the carbons, it will pass through the heat coils, and fuse the wire, opening the circuit toward the exchange. The heat produced would, in addition to fusing the wire, melt the solder which holds the sleeve *d*, Fig. 178, in place; and as a result, the pressure of the outer spring would push the heat coil down till the pin, driving before it the strip *e*, Fig. 177, would press it against the strip *f*, thereby grounding the line, and affording a safe path for the current.

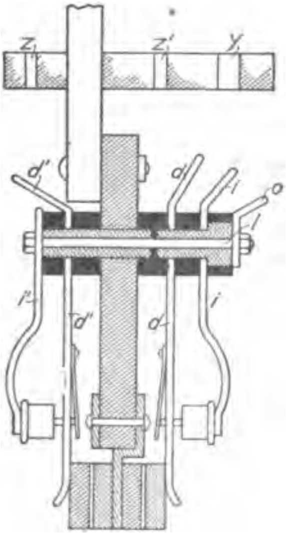


Fig. 180.

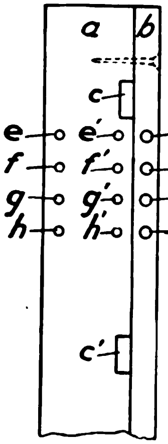


Fig. 181.

In Fig. 180 is shown the 4b arrester, and it differs from the 4a only in the method of mounting the springs. It will be seen that the lug *o* is electrically connected through the bolt *l* to the spring *i'*, while the remaining springs are insulated from one another. The wires of the outside cable are soldered to the lugs *d* and *d'*, while the cross-connecting wire is fastened to the lugs *o* and *i*. In every other respect, and in the action, this style of arrester is identical with that already described. In Fig. 181 is shown part of a vertical fanning strip, not shown in Fig. 175, but which is mounted on the horizontal flat irons *c*, *c'*, etc. This consists of two parts, one shown at *a*, being comparatively wide, and having recesses cut in it for the iron braces to pass through. A second narrow strip *b*, is screwed on to the side of *a*, and serves to hold the latter rigidly. In *a* are drilled two rows of holes, *e*, *f*, *g*, *h*, etc., and *e'*, *f'*, *g'*, *h'*, etc. They are about $\frac{1}{8}$ inch in diameter. In *b* is drilled a row of holes *i*, *i'*, *i''*, *i'''*, etc., of a diameter of $\frac{1}{4}$ inch. In a 4a frame, the wires from the switchboard are passed through the smaller holes, while the cross-connecting wire is passed through the larger. The vertical spacing between the holes is $\frac{1}{2}$ inch, the same as that between the arrester springs. In the 4b frame, the conductors of the cable pass through the small holes, but the cross-connecting wire passes through the large ones. In Fig. 177, the plan of the fanning strip is shown at *x*, the hole for the cross-connecting wire at *y*, and that for the switchboard wires at *z* and *z'*. In Fig. 180, the cable conductors pass through the holes *z* and *z'*, while the cross-connecting wire passes through the hole *y*.

SWITCHBOARD.

The switchboard is that piece of the apparatus in which the lines are so arranged that the proper connections can be made.

In the most simple form of switchboard, all the lines terminate within reach of one operator who is thus enabled to handle all the business. The essential parts of such a switchboard may be defined as follows: First — the line terminals, designed and placed to enable the operator to connect herself with each and all of the circuits. Second — the line signals, constructed and placed to give notice to the operator when the subscriber wants attention. Third — the necessary connecting circuits, for establishing the proper connections between the line terminals, and also to enable the operator to connect herself with any line terminal to learn the wish of the subscriber. Fourth — a key wired to each connecting cord circuit, to enable the operator to cut in her telephone circuit on the connecting circuit for the necessary conversation with the subscriber. Fifth — a signal placed on each connecting-cord circuit to enable the subscribers to signal the operator upon the completion of a conversation, in order that the connection may be taken down. Sixth — an additional key placed on each connecting-cord circuit to enable the operator to cut in on it and an alternating current of suitable potential to enable the operator to call the subscribers.

The line terminals are called *jacks.* They are made of brass of various designs, and so constructed as to be placed in rows. The line signals take the form of magnetic drops, and are called *line drops.* The connecting-cord circuit is wired permanently to the switchboard, and terminates at both ends in a flexible cord and plug for inserting into the jack. The circuit of a switchboard is shown in Fig. 183. Two subscriber lines are shown, and for convenience, one is shown terminated on a 4a distributing board, while the other is shown terminated on a 4b board. Referring to the upper one; the cable conductors terminate on the horizontal side, the wavy lines denoting the cross-connecting wires. At *b* and *b'* are shown the carbon-block lightning arresters, and at *c* and *c'* the heat coils. Referring to the lower line, the cable conductors are terminated on the vertical side of the distributing board, the lightning arresters being shown at *b*, *b'*, and the heat coils at *c*, and *c'*. As before, the wavy lines denote the cross-connecting wires. The two line jacks are shown at *d* and *d'*, and are constructed as follows: Referring to the upper one *e* is a brass ring shown in section 1, a German-silver spring, which normally makes contact with the point indicated by the arrow. To this contact is wired one side of the drop, the other side being permanently connected to the ring. The drop is shown at *x* and consists of the ordinary form of electro-magnet, with a pivoted armature and a brass shutter, which is allowed to fall when the former is attracted to the pole pieces. The two plugs of the operator's cord circuit are shown at *p* and *p'*. Each one consists of two metallic parts insulated from one another (called the tip) shown at *3* and *5*. The shank or sleeve is shown at *4* and *6*. The two flexible cords extend from the two plugs to the connectors *w* and *w'*, and w_1, and w'_1, respectively.

At R and R″ are shown the two ringing keys, used for throwing the alternating current onto the line to call the subscriber. Each one of these keys consists of two normal German-silver springs 9 and 10, which with the key in the position shown, make contact with the points 11 and 12 respectively. This circuit is connected to the outer spring 7 and 8. At *m* is shown the ***clearing-out drop***, or drop connected to the connecting-cord circuit to give the signal to the operator upon the completion of the conversation. The drop is permanently bridged across the circuit, and must be of high impedance. It is wound to a resistance of 500 ohms.

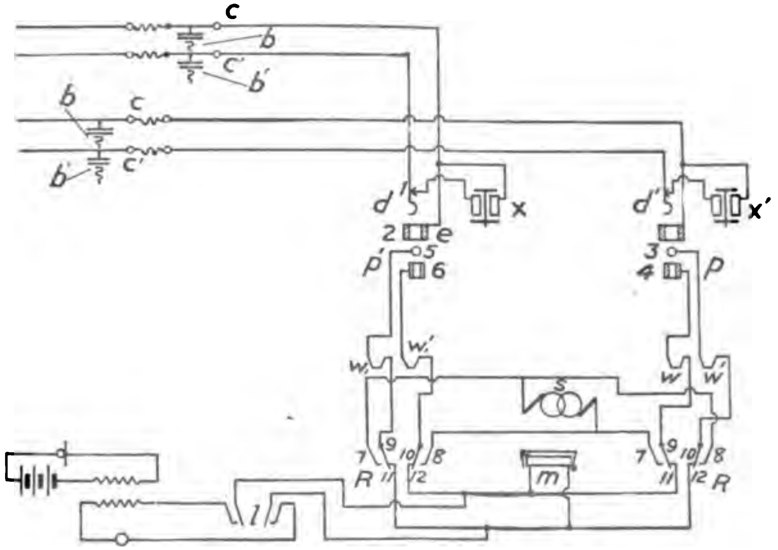


Fig. 183.

At *l* is shown the listening key. This differs from the ringing key in that there are no inner contacts. The normal springs are bridged across the line, and the outer ones are connected to the operator's telephone circuit. The ringing current generator is shown at *s*. The method of operating is as follows: One of the subscribers, for example the one whose line is connected to the jack *d*, desiring to converse with another one, rings with the generator at his telephone and throws the shutter of the drop *x*. The operator upon seeing the drop fall, introduces the plug *p'* into the jack, the tip 5 touching the spring 1, while the shank 6 makes contact with the ring 2. The spring 1 is raised, breaking contact with the drop at the arrow point. The drop is thus cut off. This is necessary, otherwise the presence of the drop bridged across the line would seriously reduce transmission as has already been explained in connection with the series bell. A circuit is now formed from the jack through the tip and sleeve of the plug and the cord, to the normal contacts of the ringing key *R′*, thence through the inner contacts 11 and 12 to the cord circuit wiring. The operator, by adjusting her listening key *l*, cuts her telephone in on this circuit and communicates with the subscriber. Upon learning that the calling subscriber wishes to communicate with the subscriber whose line is connected to jack *d′*, she introduces the plug *p* into the jack, thereby cutting off the drop *x′* as already described. The ringing key R is then depressed with the result that the ringing current is thrown on the line, thus ringing the bell at the called subscriber's telephone. It should be observed that when the bell at a subscriber's station is rung, the cord circuit is open towards the other one. The reason of this is that the calling subscriber who is waiting with the receiver at his ear would otherwise receive the very unpleasant sensation of having the ringing current pass through its coils when held in that position. Again the presence of the calling subscriber's receiver bridged across the line would shunt so much current that the called subscriber's bell would ring very faintly if at all.

During the conversation the two-line drops *x* and *x′* are cut off from their respective lines, and the only signal within reach of either subscriber is the clearing-out drop *m*. Upon the completion of the conversation the act of one or more of the subscribers ringing, throws the clearing-out drop, thus giving the signal to the operator that the connection must be taken down. The operator can, by means of her listening key *l*, listen in on the circuit. The operator can establish as many simultaneous connections as she has cord circuits. The number varies from 5 to 12 according to the magnitude of the business to be handled.

With the exception of the ringing-current generator, and the operator's telephone circuit, each cord circuit is made up of the apparatus shown in Fig. 183. The ringing generator and the operator's telephone circuit are common to all the cord circuits.

When the telephone business started, there were many different systems of operating, each requiring its peculiar form of apparatus. None of these systems are now in use. Only two of them will be mentioned here. They are the *Chinnock System*, and the *Law System.* In the former, the line signals were placed together in an annunciator box, and one of the operators was detailed to watch them. Sitting at a table were a number of operators, who switched in on the subscriber line whose number was called out by the annunciator operator, and ascertained the number required. The operator then gave the calling and the called numbers to an operator placed at the switchboard, termed the switching operator, who established the connection. This system more than any other prepared the way for those now in use.

The Law system, although now obsolete, proved very successful for the uses to which it was adapted. In outline the system was as follows: All the subscribers' telephones were placed on one wire, known as the calling wire. When the subscriber wished to call the operator, he went in on the calling wire. Since all subscribers were on the same calling-wire, the party calling had to give his number and that of the party required. Upon so doing the party would establish the connection. The principal feature of this system was the fact that a very small switchboard was needed. When, however, the volume of business became heavy, it was found to be inadequate and went out of use.

Switchboards in use to-day, may be divided into two classes: *Standard* and *Multiple.* The former board is so made up that each line entering the exchange has one terminal, or jack, and only one. The multiple system is based on the fact that every line entering the exchange has a jack within reach of every operator.

Before taking up in detail the method of construction of the standard switchboard it will be necessary to say something about the nature of the construction of the essential pieces of apparatus of a switchboard. Let us take them in the order named: The type of jack used in the standard switchboard is constructed as shown in Fig. 183a. It consists of a brass casting shaped cylindrically at *a*, and cut out in the middle with a rectangular enlargement *b* at the opposite end. The cylindrical end is slightly hollowed out in the center, and the extremities are neatly turned as shown at *x* and *x'*; by means of the hole through the lug *i* the jack is screwed to the switchboard.

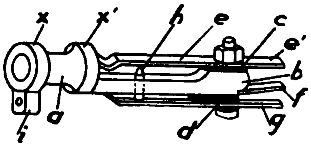


Fig. 183a.

Fastened to *b*, but insulated therefrom by the hard-rubber strip *c*, is the German-silver spring *e* the end of which is bent as shown to make contact with the tip of the plug. A second spring *g*, fastened to *b* but insulated therefrom by the hard-rubber strip *d*, is provided with a point *h*, which passes through a hole in the casting and makes contact with *e*.

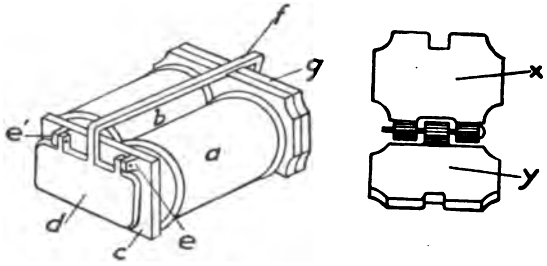


Fig. 184.

The two conductors of the subscriber's circuit are soldered to the punchings *e'* and *f*. One side of the drop circuit is soldered to *f* and the other to *g*. These jacks are usually mounted in a hard-rubber panel called the jack panel, which forms part of the face of the switchboard. Next the line signal or drop is shown in Fig. 184, where the two magnet coils are shown at *a* and *b*, and the plate upon which they are mounted, at *c*. This plate is equipped with two projections *e' e'* from which is pivoted the armature *d*. This armature has attached to it a stiff steel wire *f*, the other end of which is shaped to hold the drop *g* in place. When the magnet coils are energized, the

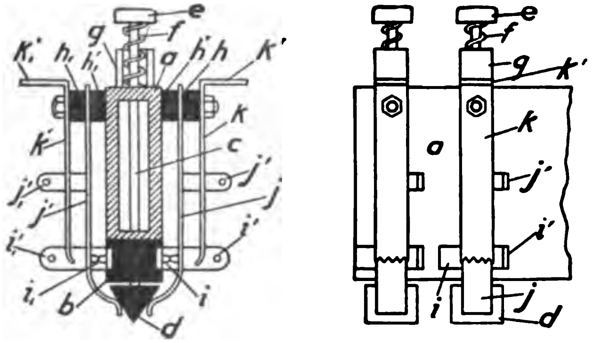


Fig. 185.

armature is attracted to the poles, lifting the steel rod *f* and allowing the shutter to fall. The face of the drop is shown at *x* and the shutter in the fallen position, at *y*. The ringing and listening keys are shown in Figs. 185 and 186 respectively. The ringing key consists of a brass frame *a* at the bottom of which is mounted a hard-rubber strip *b*. Upon this strip are mounted the contact points i i_1 with their respective lugs i' and i'_1, to which the wires are soldered. Mounted on 4 hard-rubber blocks h, h', h_1, and h'_1, are 4 springs K, j, K' and j', with their respective lugs K', j', K'_1, and j'_1. Each one of these springs is insulated from its fellows. A brass plunger *c* passes through holes in *a* and *b*, and screws into a hard-rubber wedge *d*. A hard-rubber button *e* is screwed to the top of this plunger; a spiral spring *f* which is wound around *c* has one end butting against *e*, and the other against *a*. The brass sleeve *g* prevents the button *e* from being depressed too far. The action of the key has already been explained.

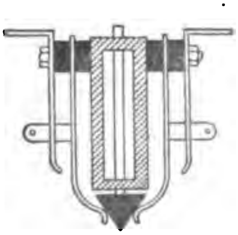


Fig. 186.

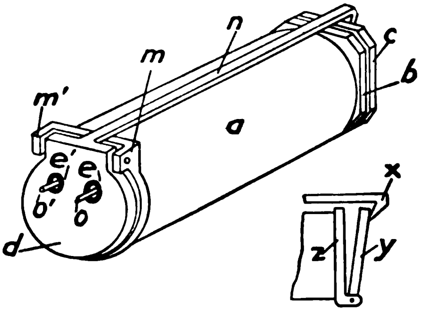


Fig. 187.

Ringing keys are usually mounted in a row, the two on each cord circuit being placed as shown in the right-hand figure. The listening key is shown in Fig. 186 and its construction will readily be understood from what has been said about the ringing key.

There remains to be described, the signals on the operator's cord circuits called the "clearing-out drops." One of these is shown in Fig. 187. It differs in construction from the line drop, in that it has only one core, which is considerably longer than those of the line drop. By actual measurement, the cores of the line drop are an inch and a half long while that of the clearing-out drop is 2½ inches long. The magnetic coil is encased in an iron shell *a*, terminating at one end in a shoulder with lugs shown at *m* and *m'*. From these lugs is pivoted the armature *d*. Two circular holes are cut into the armature, through which are brought the terminals of the coil, shown at *o* and *o'*. To prevent the coil terminals making contact with the armature, these two holes are bushed with hard-rubber rings *e* and *e'*. The face of the drop is shown at *b*, while the shutter is seen at *c*. The steel wire holding the shutter in position is shown at *n*. The catch at the end of this rod, called *the arrow*, is shown more clearly at *x*, the face of the drop being shown at *z* and the shutter at *y*. Since these drops are always in the circuit, and since several of them are placed side by side, it is necessary to equip each one with an iron shell *a* to prevent cross talk by their mutual electro-magnetic induction. The action of the shell is to short circuit the lines of force, emanating from the coil so that no field will be present in the surrounding space to affect the coils of the adjacent drops.

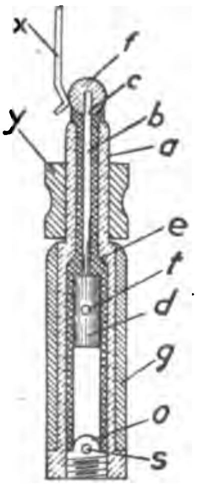


Fig. 188.

The plugs which form the terminals of the cord circuits, deserve notice. One of them is shown in Fig. 188. It consists of a hollow brass cylinder *a* turned down at one end into a shank. Placed inside of this is a hard-rubber sleeve *e*. Through the center of the sleeve is a steel bolt *b* enlarged at one end as shown at *d*. Onto the opposite end is screwed a brass ball, called the *tip* and shown at *f*. Fitting over the brass cylinder is a fiber sleeve *g*. One conductor of the cord circuit is connected to the

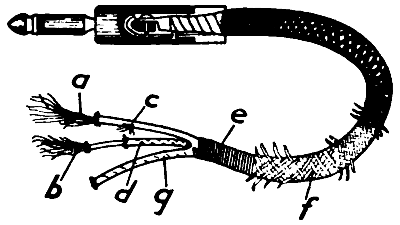


Fig. 189.

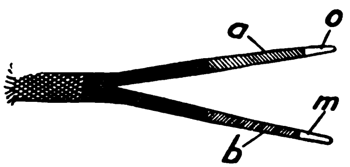


Fig. 190.

tip of the plug by a screw fitting into the hole *t;* while the other conductor is connected to the shank by a screw fitting into the hole *s*. It will be seen that the tip is completely insulated from the shank by means of the hard-rubber sleeve *e*. The fiber sleeve *g* is provided to afford an insulated handle for the operator to take hold of. At *x* and *g* are shown the spring contact and the ring of the jack respectively, thus illustrating the condition when the plug is introduced into the jack.

In Fig. 189 is shown a flexible cord, which, as has been stated, forms part of the connecting circuit. It consists of two strands *a* and *b*, each made up of many fine copper threads so as to be very flexible. The straining cord is shown at *g*. They are covered with two windings of cotton braid shown at *c* and *d*. Over the two is wound a brass spiral *e*, which protects the strands from mechanical injury, and yet retains the flexibility. Over this spiral are wound three layers of heavy cotton braid shown at *f*. One end of the cord is shown entered into the plug, which, while it is of a somewhat different design from that shown in Fig. 188, yet retains the same essential features. The opposite end of the cord is shown frayed out. In actual fact, each strand terminates in some form of terminal to enable it to be readily connected to and disconnected from the ends of the cord circuit wiring.

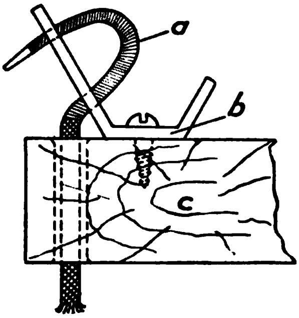


Fig. 191.

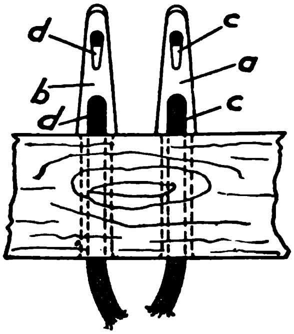
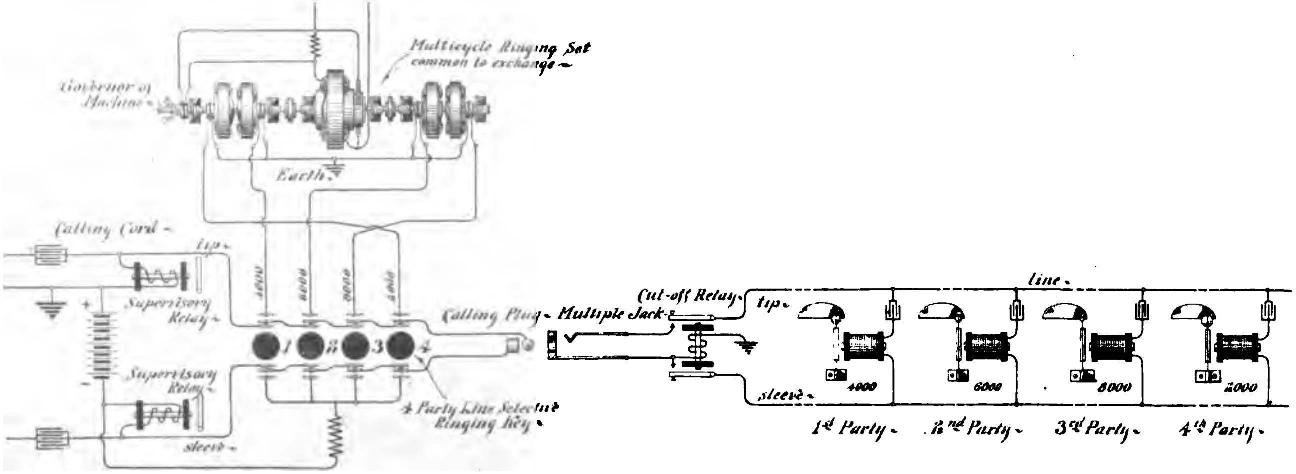


Fig. 192.

One method of terminating the strands is shown in Fig. 190. It consists of soldering the ends of the two strands to two spirals made of brass wire and shown at *a* and *b;* the soldering portions being shown at *m* and *o*. These spiral springs are quite flexible, and in addition form good electrical contact. The method of using them is shown in Fig. 191, where a peculiarly shaped brass punching shown at *b* is screwed to the upper surface of the board *c*, called the *cord shelf.* To the short lug of this punching is soldered the wire of the connecting circuit. The long lug is perforated by two holes through which is threaded the spiral, in the manner shown at *a*. The two punchings forming the terminals of the two sides of cord-circuit wiring are placed side by side on the cord shelf as shown in Fig. 192, the long lugs being shown at *a* and *b*, and the portions of the spirals threaded through the holes at *c c* and *d d*.



KELLOGG HARMONIC FOUR-PARTY SYSTEM.

TELEPHONY.

PART IV.

TELEPHONE EXCHANGES.—(Continued.)

Switchboard Cable and Switchboard Wire. It has already been shown that the lines are brought from without to the main distributing board either in lead-covered or braid-covered cables, and that they are brought across to the switchboard side of this piece of apparatus by cross-connecting wires.

All lines running from the main distributing board to the switchboard, with the exception of those carrying the transmitter battery current, ringing current, and whatever other comparatively heavy current may be provided, are carried in what is known as a *switchboard cable*. This cable is made up in various sizes, the number of pairs of conductors varying with the work required. For standard boards, the cable is made up of 20 pairs for working purposes, and one or two extras called *spare pairs*, to be used in the event of the failure of any of the regular pairs. The wire used is No. 22 B. & S. gauge, tinned; the insulation consists of a layer of silk thread wound over the wire, and a superimposed layer of cotton thread. This insulation is technically known as *double silk and cotton*. The pairs are bound together by two layers of dry paper, over which is wrapped a layer of tin foil. The outside cover consists of two layers of heavy cotton braid saturated with powdered soapstone and painted. One conductor of each pair is covered with colored cotton thread while its mate is white.

In all switchboard cables used by the Bell companies, and in those used by the large independent companies, a system of coloring is maintained, to assist in distinguishing the pairs. The arrangement of the colors is as follows: Blue, Orange, Green, Brown, Drab or Slate, Blue and White threads mixed, Blue and Orange mixed, Blue and Green, Blue and Brown, Blue and Slate, Orange and White, Orange and Green, Orange and Brown, Orange and Slate, Green and White, Green and Brown, Green and Slate, Slate and White. The colors for the two extra, or spare, pairs are usually Red and White, and Solid Red. These cables are oval in cross-section, the longer diameter being about an inch, and the shorter about $\frac{5}{8}$ inch. In order to make the proper connections, the cable must be fanned out or formed, as it is called, and before this is done the location of the lugs or terminals to which the wires are to be attached must be known.

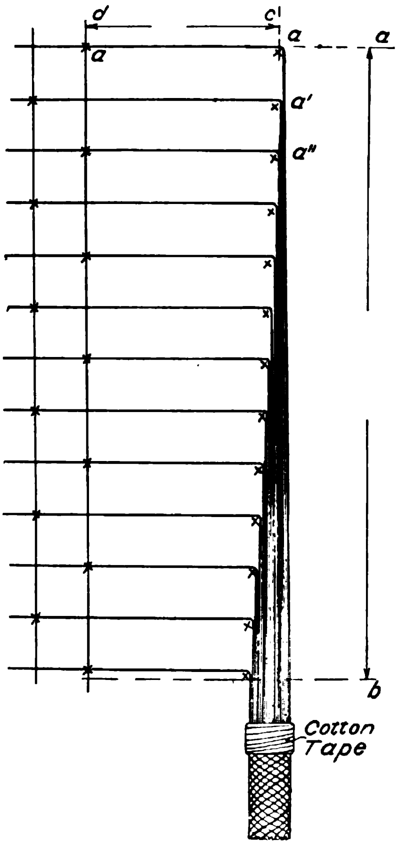


Fig. 193.

In making a cable, the following points of information should be obtained, as shown in Fig. 193. The distance between the highest and the lowest lugs; the distance from the surface on which the cable is to rest, to the line of lugs farthest removed. In the illustration, the first distance is that between the lines *a* and *b*; and the second distance, that between *c* and *d*. To the sum of these two distances is added two inches, which gives the distance from the end of the cable to which the lead and braid covering is to be removed. This distance is called the "skimming length". This having been done to expose the conductors, the edge of the braid covering is bound tightly with cotton tape as shown. This point is called the butt of the form. The opposite end *a* is called the tip. Wire nails about two inches in length are then driven into a board in a line, with a spacing equal to that between consecutive lugs. The nail heads should be allowed to project about one inch. The cable is then laid down on the board, with the stripped portion against the nails, the butt being one inch from the first nail. It is then securely held in place by two or three leather strips placed over the unstripped portion and fastened with screws. There are two ways of forming a cable—one is to have the blue wire at the tip, and the other is to have it at the butt. This latter form is resorted to only for special purposes.

Assuming the blue wire to be at the butt, the blue wire with its mate is drawn out, and bent around the first nail, as shown at No. 1, Fig. 194. The orange wire with its mate is bent around nail No. 2; green around No. 3; brown around No. 4, etc., until all wires have been so treated. It should be noticed that if the form is to be that shown in Fig. 193, and the spacing of the nails equal to that between consecutive lugs, as *a a′*, the blue wire will be bent around the first nail, and the second around No. 2; the orange wire around No. 3 and its mate around No. 4, etc. The wires having been all thus treated, the wires are held in position by a linen thread wound around the cable to bind it at the points where the wires bend at right angles. For this purpose, the best quality linen thread should be used, and it should be thoroughly saturated with melted wax before using.

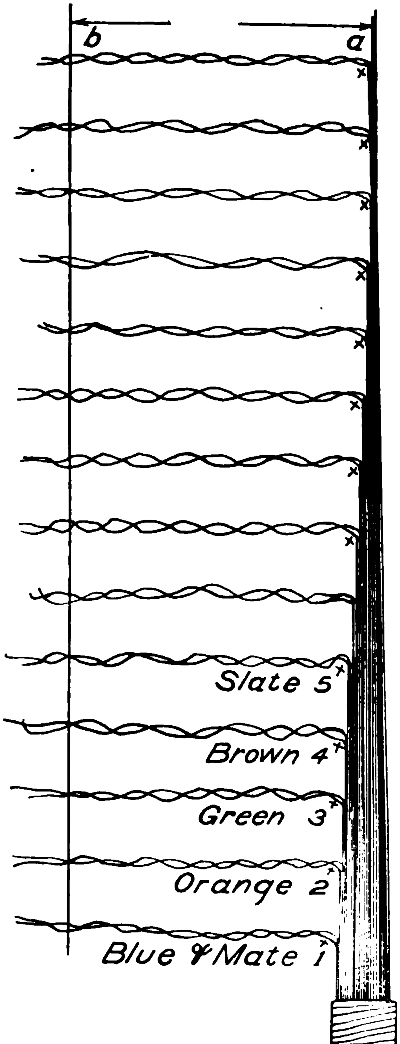


Fig. 194.

In Fig. 195 are shown two methods of winding on this thread. That at the top is the better for giving a binding hold. The form having been thus securely bound together, a distance is measured off along the wires from the line of nails at right angles to the cable, equal to the distance from the surface on which the cable is to rest to the line of lugs. In Fig. 194 this distance is shown between the lines *a b*, and at this point the insulation is cleaned off each wire. In the case of the form shown in Fig. 193 two distances must be measured alternately, first to the farthest line of lugs, and second, to the nearest line. The wire is cut off, one inch from the point where the insulation ends, to allow for working. The form is then saturated in melted wax, in the same manner as that adopted in connection with paper cables. The form having been saturated, it is given a coat of shellac and allowed to dry.

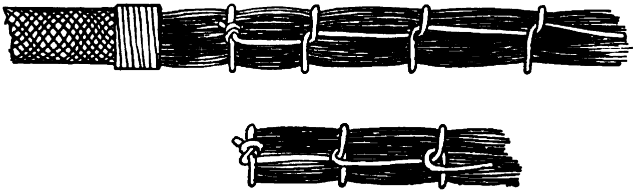


Fig. 195.

The cable is then ready for placing, and in so doing it is laid in place and securely held by pieces of leather, such as is used for belt lacing, placed around the form at intervals of about 15 inches and held to the wood by screws. The wires are then drawn through the holes in the lugs, bent over sharply, and soldered. When the solder is cool, the free ends of the wires are cut off close to the lug, and the job is finished.

In soldering, great care should be taken to have the soldering iron thoroughly heated. It should then be placed on the lug at the point where the wire passes through the hole, until the lug itself becomes hot enough to make the solder run.

In making a form for the end of the cable that is to be connected to the jacks, the same method is adopted. The nails are driven in at intervals equal to the spacing of the jacks as they are placed in the switchboard, and the pairs are formed together. In wiring between the jacks and the drops, or between any two points not far removed, it is often most economical and convenient to make a cable out of switchboard wire. It is done as shown in Fig. 196. The wire used is No. 22 B. & S. gauge, double silk and cotton insulation, two conductors twisted together to form a pair. The two conductors are distinguished from one another by the different coloring of the insulation. In making a form of this kind, both ends must be done at the same time, and at each form two rows of nails must be driven in. These two rows at one end are denoted by the numbers 1 to 5, for the inner row, and 1^1 to 5^1, for the outer. At the other end they are called by the numbers 1^1 to 5^1 for the inner and 1^1_1 to 5^1_1 for the outer. The distance between the two rows is one inch in excess of *a b* in Fig. 194. The end of the twisted pair is wound around nail No. 1^1, so as to be held securely, and brought around No. 1, thence to No. 1^1 to 1^1_1, to No. 2^1_1 to No. 2^1, to No. 2, to No. 2_1, to No. 3_1 to No. 3, to No. 3^1, to No. 3^1_1, to No. 4^1_1, to No. 4^1, to No. 4, to No. 4_1, to No. 5_1, to No. 5, to No. 5^1, ending at No. 5^1_1. The form is then sewed up in the manner already described, except that the sewing extends the whole length of the cable. By cutting the wire between nails 2_1 and 3_1, 4_1 and 5_1, 1^1_1 and 2^1_1, 3^1_1 and 4^1_1, there remains a made-up cable having 5 pairs. A cable of this kind can be made with a capacity of almost any number of pairs. It is seldom made, however, with a capacity larger than 20 pairs. From this point the treatment of the cable is identical with that already described.

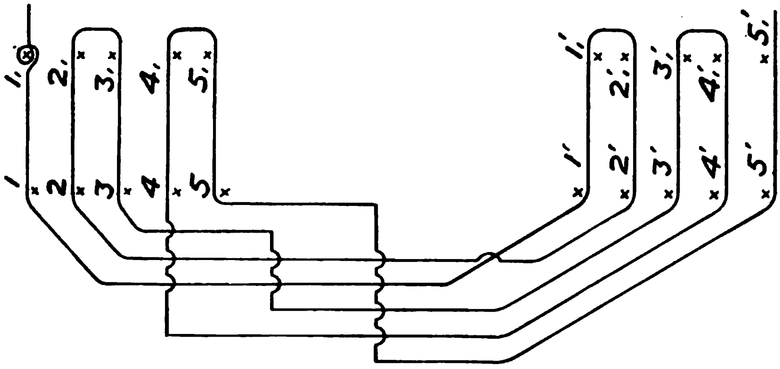


Fig. 196.

Switchboard cables, or cables made up of switchboard wire, should never be placed in damp places, or where water is liable to reach them. In small exchanges, the best method is to build a false floor upon the real one; the false floor being of sufficient height to accommodate beneath it all the cables necessary. Perhaps a safer method is to construct a galvanized sheet-iron duct, made water-tight and placed beneath the floor. This need not be done, however, except when the exchange is damp, or where it is impossible to construct a false floor.

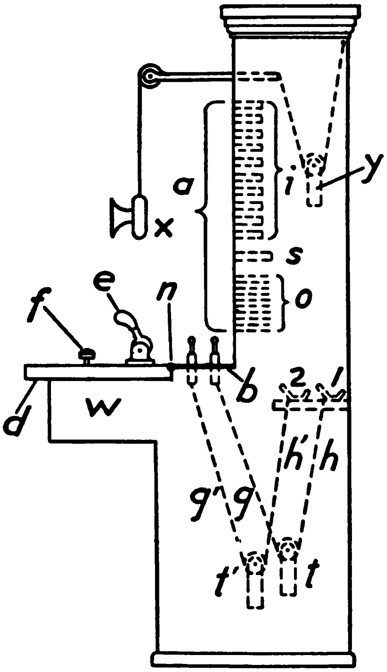


Fig. 197.

In Fig. 197 is shown the end elevation of a standard section of switchboard. The framework is made of mahogany, the height over all being about 6 feet. The portion of the framework enclosed in the bracket *a* is called the *face of the board*, and on it are mounted the line drops *i*, the clearing out drops *s*, and the jacks *o*. Of the horizontal portion that marked *b* is called the *plug shelf*. It is about six inches wide and covered with sole leather, shown by the shaded portion. It is drilled for two rows of holes through which the cords pass, and against the edges of which the plugs rest when the cords are not in use. The two plugs on the same end circuit are placed on a line; the one nearest the face of the board (usually referred to as the *answering plug*) is for answering calls; the one farthest from the face (referred to as the *calling plug*) is for calling subscribers. The answering and calling plugs are placed on two lines parallel to the face of the board. The cords are shown by dotted lines at *g g'* and *h h'*. Each one passes through a pulley attached to a weight which ensures the plug returning to its position on the plug shelf. The two cord weights are shown at *t* and *t'*. The cords are shown attached to their respective fasteners 1 and 2 placed on the cord shelf. These fasteners are placed in two rows parallel to the face of the board, one row for the answering and the other for the calling cords. The portion of the board *d* is called the keyboard, from the fact that the listening and ringing keys are mounted thereon. One listening key is shown at *e*, and a ringing key at *f*. The listening key is placed directly in front of the pair of cords to which it connects the operator's telephone circuit. The ringing keys are placed, one just to the right and one just to the left of the two plugs to whose circuit they are wired. The ringing keys and the listening keys are each placed in a line parallel to the face of the switchboard. The keyboard is hinged to the plug shelf at *n* so that it can be raised to give access to the keys and wiring. It closes down on a wooden trough *w*. The transmitter *x* is suspended by the two transmitter cords which form the circuit, and which are similar in construction to, but lighter than, the cords

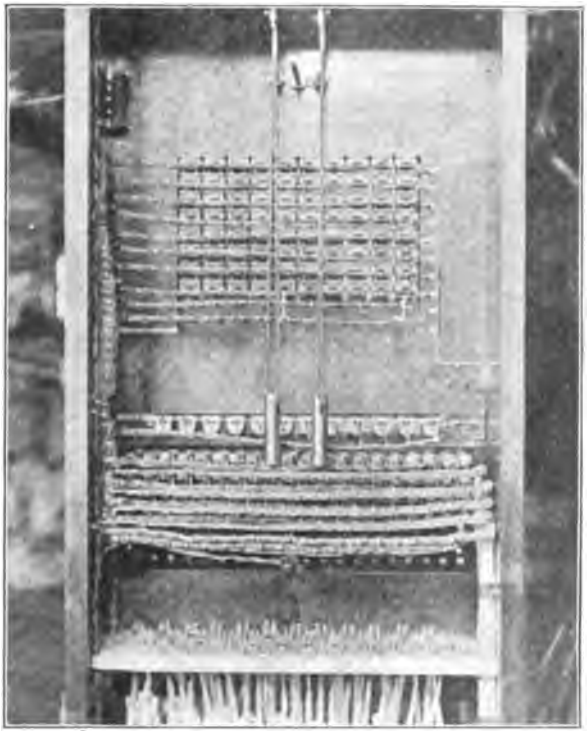


Fig. 198.

used on the connecting circuits. The cords run over two weighted pulleys, one of which is shown at *y*.

Fig. 198 is the rear view of the same board. Near the bottom is seen the cord shelf with the two rows of cord fasteners to which the cords are attached. The cords are also seen passing through the cord shelf from below. Some of them are knotted—a practice resorted to when the cord is too long to keep the weights from striking against the floor when the plug falls into its seat on the plug shelf.

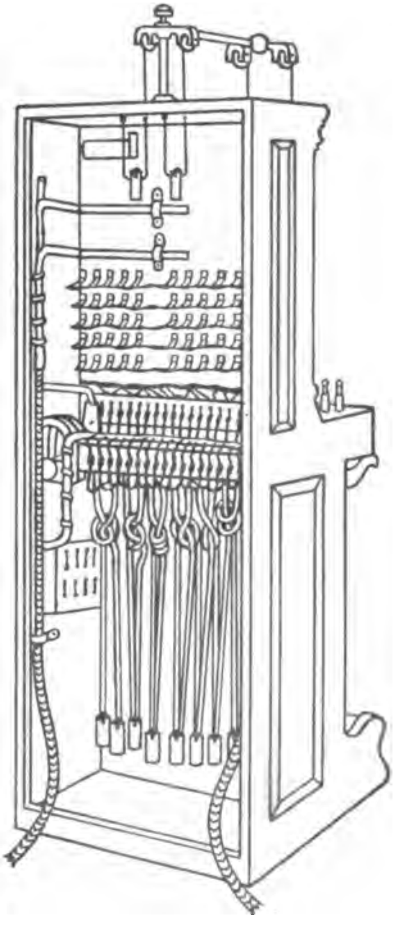


Fig. 199.

A short distance above the cord shelf is seen the hard-rubber jack panel. This panel is drilled for 120 jacks, but is equipped with only 80. The bottom row of vacant holes can be seen. The switchboard cables carrying the lines rise on the right-hand side of the board, and bend horizontally to take the jacks. The forms and the sewing are shown. The clearing-out drops are in a row just above the line jacks. These are 12 in number. The line drops are placed above the clearing-out drops. The board has a capacity of 10 rows of 10 drops each, 8 rows only having been placed. The hand-made cable, rising from the jacks to the line drops, can be seen on the left-hand side. The cord circuit wiring from the cord fasteners is placed on the under side of the cord shelf, and is therefore invisible. The hand-made cable from the keys to the clearing-out drops, rises in the forward corner of the left-hand side of the board. In the upper left-hand corner is the operator's induction coil, and the wiring to it is seen in the foreground on the left-hand side. The transmitter cords are attached to binding posts screwed to the roof of the boards; and the transmitter cords with their weights.

At the right-hand side of the line-drop panel, and passing down to the clearing-out drops, is what is known as *the night-bell circuit.* It is of comparatively heavy wire, and soldered to lugs opposite each row of drops. From these lugs the circuits are continued to small contacts placed on each drop just beneath the shutter, so that when a shutter falls this circuit is closed, and a buzzer, which is wired in series, caused to sound.

It should be observed that, though the switchboard is only partially equipped with jacks and drops, wiring has been placed for the accommodation of the full number of circuits. This is done as a measure of economy; if an increase in the equipment is desired at some future time, all that is necessary is to place the additional jacks and drops and solder the connections.

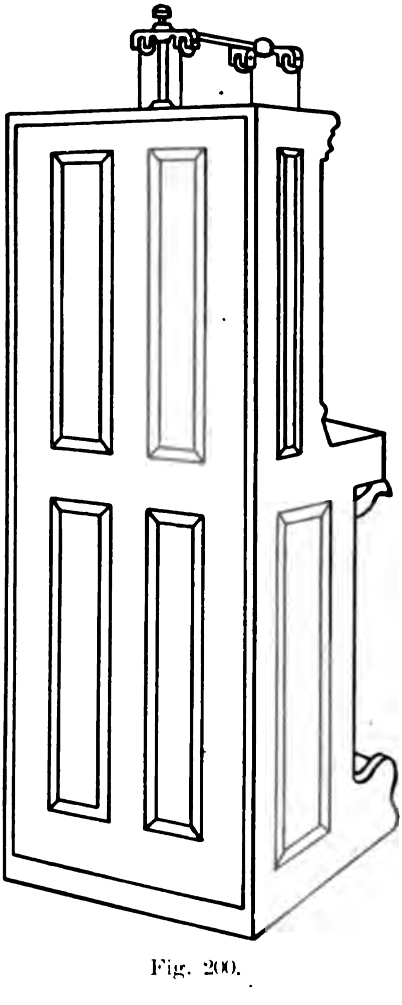


Fig. 200.

In Fig. 199 is shown a slightly modified form of this type of board in which the full length of the framework is seen. In addition to the apparatus already shown, the ringing current hand generator is seen on the left-hand side. In Fig. 200 is shown the same switchboard with the rear shutter in place. This shutter is provided to keep out the dust.

The forms of switchboards already shown have a capacity of 100 lines. This number is about all that one operator can handle. In fact, when the calling rate exceeds 4 calls per day per line, one operator cannot successfully handle more than 80 lines. Therefore when more than 80 to 100 lines have to be brought into a switchboard, a new section must be placed beside the first, and the additional lines connected thereto. Under these conditions, should a call from a subscriber, whose line terminates on one section, be received for a line which terminates on the other section, the operator can easily complete the connection by reaching across to the required switchboard.

Office Trunks. When it becomes necessary to place a third section of switchboard to handle the increased business, a new condition presents itself. Calling the first or original section A, the second B, and the one last installed C, it will be evident that the operator at A, can make connections between lines whose jacks are on the A and B sections respectively, but cannot complete a connection between a line whose jack is on A section, and one whose jack is on C section. The operator sitting at the B section can, however, complete connections between any lines in her section, and any other one in either A or C. The operator at the C section is similarly situated to the one at the A section, and her work is similarly limited. To sum up, each operator, in addition to being able to complete connections between lines the terminals of which are on the board before which she sits, is also able to complete connections between lines, one of which has its terminal on her section, and the other on an adjacent section. It must become evident that some means must be provided for the operators to complete connections between two lines, which under the present conditions are not accessible. If, for example, the operator sitting at the A section were provided with one or more circuits, running between her section and C, then these circuits could be used to establish connections between the two boards. This is the method used in overcoming this difficulty.

As has been stated, trunk lines are those running between two exchanges. It is necessary here to expand the term to include lines joining non-adjacent sections of switchboard in the same exchange. This class of trunk is referred to as *office trunk* or *stripping trunk.* With the office trunk, the number of sections of switchboard in an exchange can be increased indefinitely, as far as the practicability of establishing connections is concerned. There comes another limitation, however, which will be discussed later. These office or stripping trunks, when they were first introduced, were wired like a subscriber line, with a drop placed on each one of the two sections that they connected, as shown in Fig. 201. A trunk wired in this manner can be used for calls in both directions. For example, should the operator at A receive a call for a subscriber whose line terminates at C, she would introduce her calling plug into the trunk jack, thereby cutting off the drop at that end, and ring down the drop at C. The operator at C, upon plugging, would cut off the drop at her end. The operator at A having informed the one at C of the connection required, the latter, leaving the answering plug in the trunk jack, introduces the plug of the calling cord into the jack on the called subscriber's line and rings in the usual manner. Upon the called subscriber answering, a circuit is established through his line to the operator's cord circuit at C, through this to the office trunk, thence through the cord circuit at A to the calling subscriber's line. Should the call originate at C, for a line terminating at A, the same process is gone through, but in the opposite direction.

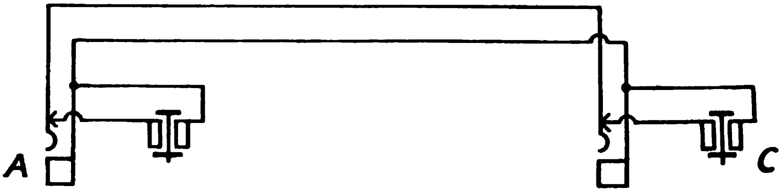


Fig. 201.

In Fig. 202 is shown a complete connection established in this manner. The details can be readily followed. It will be seen that there are two clearing-out drops bridged across the circuit; one at the A section, and the other at the B section. This condition is not desirable as it tends to cut down transmission, and therefore attempts were made to change the wiring of the office trunk. A further reason for desiring to make a change, was due to the fact that the number of calls that can be handled on a trunk of this type is limited; and therefore if the business is heavy, the number of such circuits will necessarily be excessive. The change adopted was to divide the number of such trunks in two, using one half for handling calls from A to C, and the other half for calls from C to A. The drops were removed and the incoming end wired to cords and plugs. The drops being removed, it was necessary to provide some other means of transmitting the information concerning the call, from one operator to the other. To this end a special circuit called an *order circuit*, *order wire*, or *call circuit* was provided. Experience soon proved that it was advantageous to have two such circuits, one for transmitting information from A to C, and the other for transmitting it from C to A. At the sending end, the circuit is wired to a key, which acts in the same manner as the listening key. The other end is wired directly to the telephone circuit of the operator. Thus by depressing the key at the sending end, the operator at that point puts herself into direct communication with the operator at the distant point.

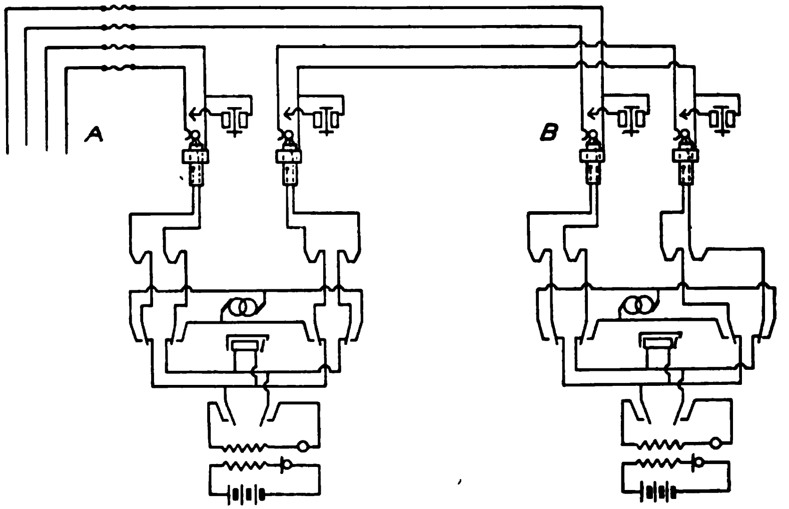
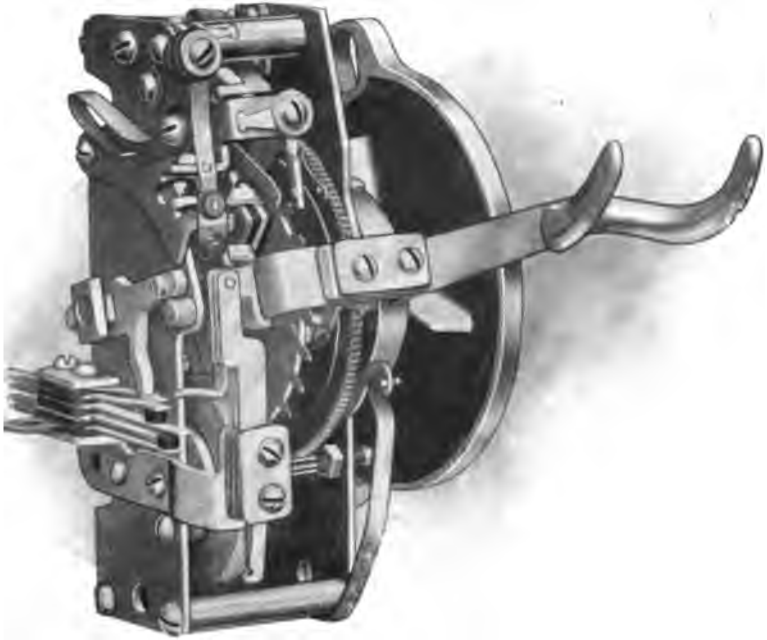


Fig. 202.

The trunks in each group are numbered from one up. At the sending end these numbers are stamped in the hard rubber beside the jack, and at the incoming end, they are stamped in the



ANGLE VIEW OF REAR OF CALLING DEVICE ON TELEPHONE.

Automatic Electric Co

leather of the plug shelf directly in front of the trunk plug. Suppose that the operator at A has a call for a line terminating on C. After answering the subscriber, she would depress the key of the order wire and say to the operator at C, "give me 250", that being the number of the called subscriber's line. The operator on C would answer, "Take it on 1", 1 being the number on the trunk assigned, and taking up the plug on trunk No. 1 would introduce it into the jack of the called subscriber's line. The operator at A, having received the assignment, introduces the plug of the calling cord into the jack of trunk No. 1, thus completing the circuit.

Had the call come first to the operator at C, for a number on the A section, she would depress her order-circuit key, connecting herself with the operator's circuit at A and say: "Give me 15", 15 being the number called for. The operator A would then answer, "Take it on No. 1", No. 1 being the number of the trunk assigned and introduce the plug of that trunk into the called subscriber's jack. The operator at C would then plug with the calling cord into the jack on trunk No. 1, thus completing the circuit.

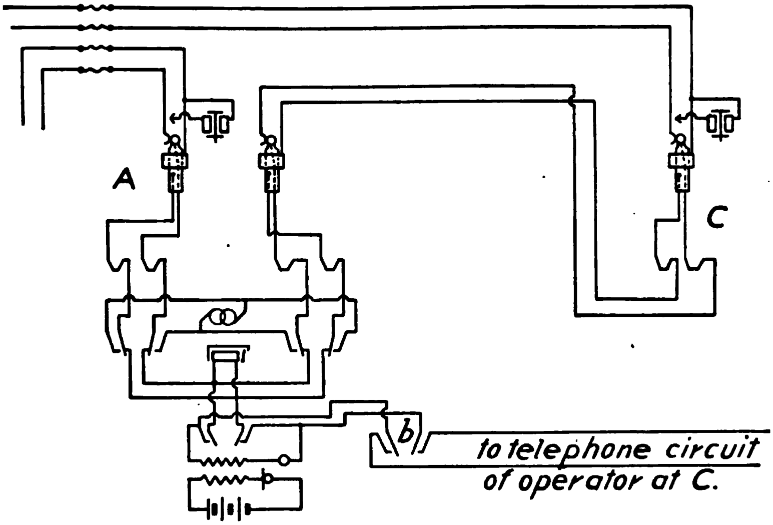


Fig. 203.

It must be remembered that the order circuit used by the operator at A to transmit calls to C is separate and distinct from that used by the operator at C to transmit to A. Also the set of trunks used for completing connections from A to C is separate and distinct from that used for completing connections from C to A. The No. 1 referred to in the first case is therefore not identical with that referred to in the second.

In Fig. 203 is shown a connection established between a subscriber's line on the A section and one on the C section. Here, the trunk jack at A is wired without a drop, while at the C end, the trunk ends in a cord and plug which is in the subscriber's jack. The order circuit key is shown at *b*; the normal contacts being bridged to the outer contacts of the listening key, while the outer contacts are wired to the telephone circuit of the operator at C. Upon the completion of the conversation on a connection which is completed over a ring-down trunk, both the clearing-out drop at A and C are thrown by the ring-off, so that both the operators receive the signal signifying that the connection is to be taken down.

Where a circuit trunk is used, however, the operator at one end only, receives the ring-off signal, and the operator on whose section the trunk plug is situated receives no signal whatsoever when the connection is thus taken down. In order to prevent the trunk plug being left in the subscriber's jack, thereby preventing the subscriber from calling central, and also keeping the trunk out of service, the operator upon taking down the connection, goes in on the order circuit again and orders the other operator to disconnect the trunk. This system can be readily extended to take in 4, 5, 6, 10, and more sections. When more than three sections exist, each section is equipped with a group of trunks and an order circuit to every other section except the adjacent one.

The number of sections that can be successfully handled with the above mentioned system depends upon another point which will be taken up directly. Reference to what has already been said, and to the circuits will show that every time a connection is handled over a trunk circuit, the work of two operators is required, which necessarily takes up more time than would be necessary if the work were done by one operator. When a connection is required between two lines whose jacks are within reach of one operator, the time required is that of plugging into the calling jacks, ascertaining the number desired, and then plugging into the jack on the line called for, ringing the subscriber and waiting for him to answer. When a call is trunked, the additional time taken is that necessary to reach the second operator, and to get her to make the assignment. If the second operator puts the trunk plug into the jack of the line called for at the same time that the first operator plugged into the trunk jack, no additional time would be taken up beyond that already noted. In actual fact there is always a little loss here, which further retards the completing of the connection.

Again, the fact that upon the completion of the conversation, the trunk must be ordered to be cleared causes an additional delay. The operator whose duty it is to order the trunk cleared, may at that moment be busy attending to the wants of some other subscribers, so that the trunk will remain idle, together with the subscriber line into which it is plugged. All of which tends to slow down the service. The result is that with this system an operator cannot handle as many lines as would be possible, were the necessity for trunking reduced to a minimum or eliminated altogether.

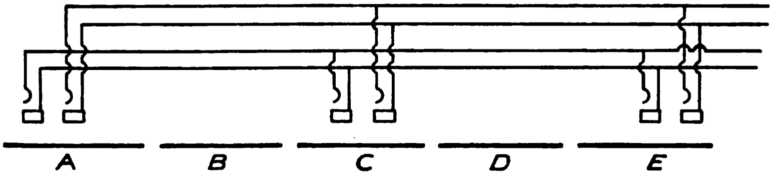


Fig. 204.

However, before this point is followed out in detail, it will be well to consider the condition arising when an additional exchange is opened. If a call from a subscriber in one of the exchanges is sent for a subscriber in the other exchange, obviously, the connection must be completed over a trunk between the two switchboards. Since all operators are likely to have a connection of this sort, the trunks between the two exchanges must be within the reach of all the operators. A little thought will show that the trunks between exchanges must be of the ring-down type, because if they were of the circuit type, they could be used only on connections that lay within reach of the section at which they terminated in cords and plugs.

It might be urged that a group of trunks could be provided for each non-adjacent section of switchboard at the other office.

This, however, would be too wasteful of trunks. It is advisable to divide the ring-down trunks into two groups: one for sending calls from one exchange to the other, and the other for sending them in the reverse direction. Each group of trunks should, at the sending end, be placed within reach of every operator and this is done by wiring them to jacks placed in every alternate section as shown in Fig. 204, where the straight lines placed above the letters A, B, C, etc., denote the sections of switchboard. Two trunks will be seen wired to jacks placed at A, C, and E. The operator at B can reach the trunk jacks at A or C, and the one at D, can reach those at C or E, so that they are within reach of every operator in the office.

At the incoming end, each trunk terminates in a jack and drop, and these jacks with their accompanying drops are distributed evenly among the sections. The calls handled over these trunks, are dealt with in the same manner as described in connection with office trunks. Let an extreme case be taken. Suppose that a call originates in one office which shall be designated by No. 1 for a connection with a subscriber's line terminating in another exchange known as No. 2, the method of completing it is shown in the following figure.

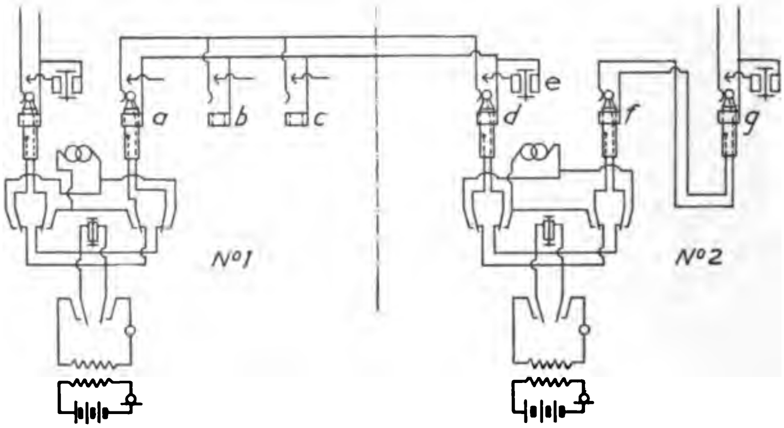


Fig. 205.

In Fig. 205 is shown a connection established over a ring-down trunk between the two exchanges. The portion on the left-hand side of the dotted line represents one exchange, No. 1, and that on the right-hand side the other exchange, or No. 2. Assuming that the call originates in exchange No. 1, the call is answered in the usual manner, and the operator at No. 1 upon learning what is required, plugs with the calling cord into trunk jack *a*, placed on or adjacent to the section at which she is sitting. The jacks denoted by *b* and *c* represent those on the same trunks placed on the other section of the same exchange, as already described. This trunk being rung on, the drop *e* at exchange No. 2 falls, and the operator sitting at the section upon which it is placed answers. Unless the number called for happens to be on the same section as the trunk jack and drop, this latter operator must make use of an office trunk to complete the connection. This is the condition shown in the figure, where *f* denotes the office trunk jack and *g* the plug of this trunk introduced into the subscriber jack.

In putting through this connection, the order must be sent, first from the operator at exchange No. 1 to the operator at No. 2 who answers the trunk. Second, from this operator to the other one in the same exchange who has access to the called subscriber's jack. This process entails a loss of time and slows down the service. Again, the condition of two clearing-out drops being bridged across the circuit is met with.

Subdivided Multiple. To do away with the necessity for repeating the call to a third operator, and also cutting out one clearing-out drop, a scheme was devised which is called a subdivided multiple. Some one section, usually one of the two end sections, is set aside for a trunk section, and on it are placed a sufficient number of jacks to have one connected to every line entering the exchange. When a trunk is called for from some other exchange, this operator answers it, and having the terminals of all the lines in the exchange within reach, is able to complete the connection herself. This was the first step towards the introduction of a full multiple switchboard.

Multiple Switchboard. The full multiple switchboard, or multiple switchboard as it is more commonly called, does away altogether with the use of the office trunks, and when the business is heavy enough it is the most economical system. For example, suppose that there are 1,000 lines to be handled in an exchange, and one operator is able to handle 100 only. With the standard system 10 sections and 10 operators would be required. If a multiple switchboard be substituted, the time saved in doing away with the use of the stripping trunk will be sufficient to enable each operator to handle maybe 200 lines, thus cutting down the number of operators necessary to handle the business by one half.

The principle of the multiple switchboard is as follows: Each line is wired to a jack and drop, placed on the section at which the operator sits whose duty it is to answer calls. This jack is called the answering jack. In addition to this jack, there appears in each section one additional jack, wired to this line. These latter are called multiple jacks, and are used by the operators in calling subscribers.

Multiple switchboards are divided into two classes: Series and Bridging, Series and Switchboard. In the former, the line runs through the multiple and answering jacks in series. In Fig. 206 is shown a subscriber's line multipled through a series board. The sections are denoted by the numbers 1, 2, 3, 4, etc., and are separated from one another by the dash lines. The multiple jacks are shown at *a*, *b*, *c*, *d*, and *e*, one in each section; and the answering jack and drop are shown at *f* and *g* respectively. They are placed on the fifth section. It will be observed that the jack is of the same type as that already shown. One side of the line is wired through the contact spring and the contact point of each jack in series, so that when a plug is introduced into any one of the jacks, the drop is cut off. Hence the name series. The two sides of the main distributing board are shown at *o* and *m*.

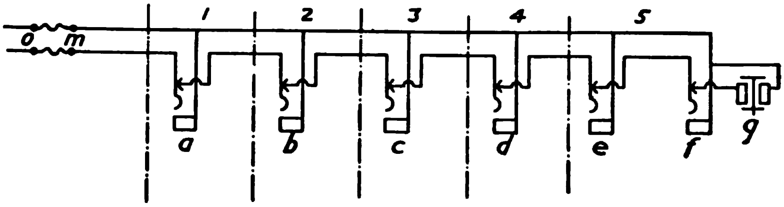


Fig. 206.

In Fig. 207 is shown a connection established between two lines *a* and *b*, both of which are multipled in sections 1, 2, 3, 4, and 5. The multiple jacks of the line *a* are shown at *j*, *k*, *l*, *m*, and *n*, and the answering jack and drop, at *o* and *p* respectively, on the "5" section. The multiple jacks on the line *b* are shown

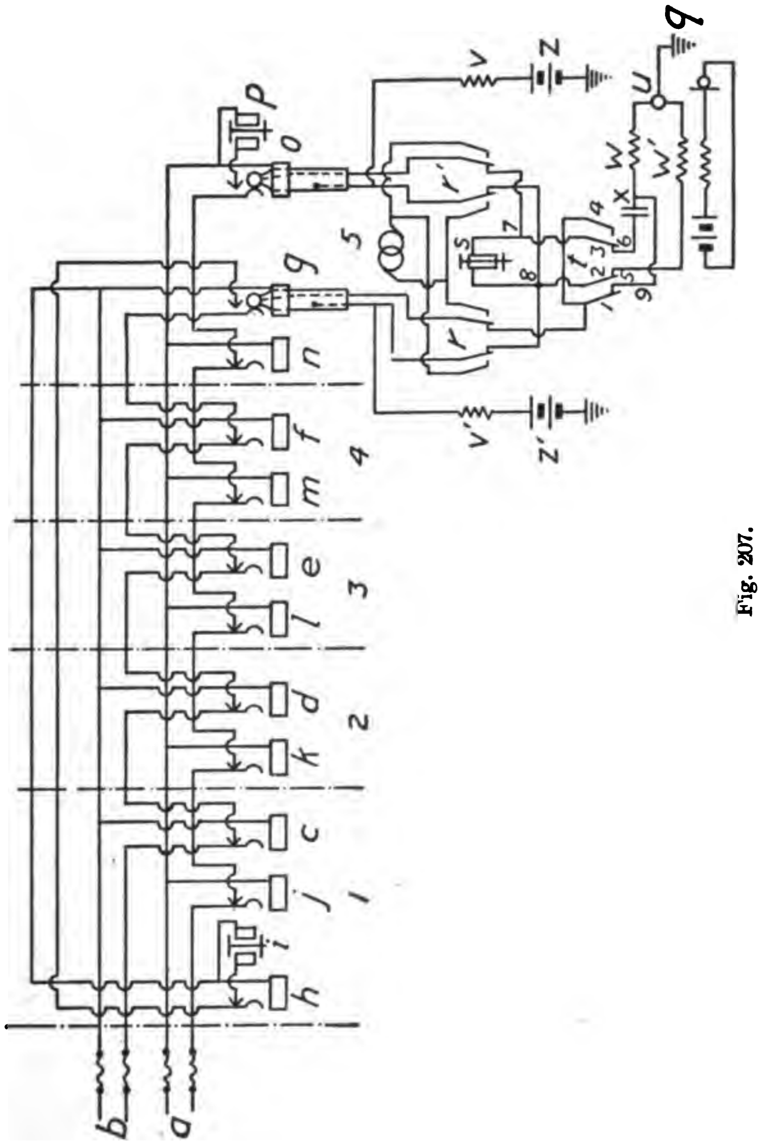


Fig. 207.

at *c*, *d*, *e*, *f*, and *g*, with the answering jack and drop at *h* and *i* respectively, on the first section. The subscriber on line *a* has called and was answered by the operator at the "5" section by introducing the answering plug into the answering jack *o*, thereby cutting off the drop *p*. The subscriber on the line *b* was called by the operator pushing the calling plug into the multiple jack *g*, thereby cutting off the drop *i*, and ringing. Had the call come in the reverse direction, that is, had the party on line *b* called, the operator at section No. 1 would have answered by pushing her answering plug into the answering jack *h*, and calling the subscriber on line *a* by going in with the calling plug at the multiple jack *j*, thereby cutting off the drop *p*.

It must be remembered that there may be anywhere from 1,000 to 8,000 lines in the switchboard, all wired as those shown at *a* and *b*. It will be evident that with this system, connections can be established and cleared in much less time than where a second operator is necessary. Furthermore, the service receives an additional impetus from the fact that the operators being relieved of the necessity of making trunked connections, have nothing else to do but to attend to the wants of the subscribers whose answering jacks are placed before them.

One feature, however, of this system is absent from the standard board. Take the case shown in Fig. 207. Suppose that, while the conversation is going on between the two parties on the lines *a* and *b*, a call comes in for either one of them from a line *x* whose answering jack is situated on section 3. Now the operator at section 3 not being able to see section 5, and not having the time to look, if she were able to see, would complete the connection by plugging into the jack *l* or *e* as the case might be, thus connecting *x* with the two parties who are already talking. This condition would, of course, be very undesirable.

To prevent this, some form of signal must be given to the other operators that these two lines are in use. The signal used in this work is called *the busy test* and is established in the following manner: First consider the operator's cord circuit shown at section 5. It consists of the two plugs and cords, the two ringing and one listening keys, and the clearing-out drop; but the wiring is different from anything yet seen. The shanks of the plugs are connected through the middle and inner contacts on one side of each of the two ringing keys *r* and *r'*. The listening key *t* is of special design and is equipped with a special spring 1, which, when in the position shown, makes connection with an inner contact point. This spring, although insulated from 2 and 3, is mechanically connected to them, so that when the key is depressed the contact is broken. Following the cord circuit from the tip of one plug to that of the other, it will be seen that after passing through the opposite side of the ringing key *r* it passes to the spring No. 1 of the listening key. Suppose this key depressed and the contacts at 1, 2, and 3 broken in consequence, and that between 3 and 4 made. The spring 1 being wired, or strapped, to the spring 4, the circuit therefore follows this path to the spring 3, thence to the point 7, from whence it passes through the ringing key *r'* to the tip of the plug at *o*. The clearing out drop is bridged across this circuit at 8 and 7.

Suppose now the operator, in order to listen, adjusts her key as shown in the figure. The connection between 3 and 4 is broken and those between 3 and 6, 2 and 5, and 1 and 9 are made. Following the circuit now from the shank of the plug to the point 8, it runs from there through the contacts 1 and 5 to one-half *w'* of the secondary coil winding. Thence through the operator's receiver *u* to the other half *w* of the winding, to the condenser *x*, to the contacts 9 and 1, and back to the tip of the plug. A bridge is formed through the condenser *x*, and the contacts 6 and 3, the point 7 to the tip of the plug at *o*. Returning from the shank, the bridge is completed at 8. Thus the operator's circuit is bridged to both subscribers.

The coil of the operator's receiver is split, the middle point being carried to ground at *q*. Wired to the shank of each plug is a battery—one shown at *z* and the other at *z'*, the circuits passing through a retardation coil, one of which is shown at *v* and the other at *v'*. When a plug is introduced into a jack, this battery is thrown on the rings of all the jacks on that line.

Under the condition shown in Fig. 207, the potential of the battery *z* would be thrown on the rings of the jacks *o*, *n*, *m*, *l*, *k*, and *j*; and that of the battery *z'*, on the rings of the jacks *g*, *f*, *e*, *d*, *c*, and *h*. The retardation coils *r* and *r'* each consist of an electromagnet with a soft-iron core, the coils having a resistance of 600 ohms. Their action is to retard or choke off the talking current, so that transmission will not be reduced or the line made noisy, while the direct current from the battery is allowed to flow whenever a path is offered. Remembering that every operator is equipped with cord circuits identical to that shown, suppose that the operator at section 2, for example, receives a call for the line *a*. By touching the tip of the calling plug to the ring of the jack, *k*, the following path will be afforded the current, which will be traced out on the cord circuit shown to save confusion by drawing another cord circuit on section 2. From the ring of the jack to the tip of the plug, thence through the ringing key to the spring 1, thence to 9, to the opposite side of the condenser *x*, through *w* to the receiver *u*. Passing through one-half of the coil on *u* it goes to ground at *q*. Every time the tip of the plug is touched to the ring of the jack, a rush of current flows to ground through this circuit causing a "click" in the operator's receiver. The presence of this click informs the operator that the line is busy.

The connection being taken down, the battery potential is moved from the rings of the jacks, so that upon an operator touching the tip of a calling plug to any of them, no current flows through her receiver to ground, and consequently no "click" is heard.

The condenser *x*, which has a capacity of 2 M.F., is needed for the following reason: When the operator tests for a busy line, the answering plug is always in some answering jack. Therefore when the tip of the calling plug is touched to the ring of the jack called for, the current would flow down to the condenser *x*, as described, and wanting its presence, some of it would pass through the listening key, out on the line of the party calling. This would result in the subscriber getting an unpleasant noise in his ear, and in reducing the strength of the busy test by shunting too much current.

The great disadvantage of the series multiple switchboard lies in the fact that on one side of the line there is a series contact at each jack, and the number of such contacts increases with the number of sections. In the series switchboard in use a short while ago at the Courtland St. exchange in New York, there were 44 sections, and consequently 44 series contacts on one side of each line. The smallest amount of dust settling on these contacts gives them an appreciable resistance, which increases with the number of jacks, and this resistance is all thrown in on one side of the line. The result is that the line becomes unbalanced and noisy. Furthermore, if the dust deposit is the least bit exaggerated, as for example from sweeping the floor carelessly, the resistance at the contacts often becomes so high as to render conversation impossible. A practical example will illustrate: In the Courtland St. exchange above referred to, the resistance between the first and the 44th section of that side of the line which passed through the jack contacts, was normally 13 ohms. At times it went as high as 50 ohms, and even to an open circuit. To overcome this defect, the idea was conceived of bridging the multiple and answering jacks across the line, and this gave use to the bridging multiple board.

Bridging Switchboard. In Fig. 208 is shown the wiring of a subscriber line passing through a bridging board. As before, the main distributing board is seen at *a*. At *b* is a new piece of

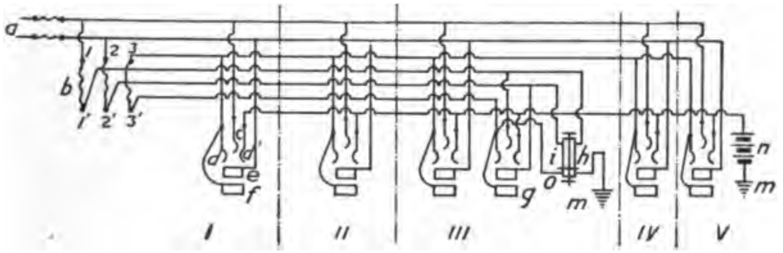


Fig. 208.

apparatus which came into use in connection with this type of switchboard, although it is also used with the series board. It is called the intermediate distributing board and its use will be described directly. There are five sections of switchboard denoted by the Roman numerals, and in each one is shown a multiple jack bridged to the line. This jack is of a different design from that previously shown. Referring to the one shown in section I, it will be seen to be made up of three springs and two rings. The springs are shown at *c*, *d*, and *d'*, and the two rings at *e* and *f*. The spring *c* forms one of the contacts of the talking circuit, the other contact being the ring *e*. A battery *n* grounded at *m* is connected to the spring *d'* on all the jacks; while the spring *d* is strapped to the outer ring *f*, and is connected to a third wire which, for the multiple jacks, runs to the contact 3 on the intermediate distributing board, and for the answering jack *g* which is shown on the third section it is run to the contact 3′. The contacts 3 and 3′, 2 and 2′, and 1 and 1′ are cross-connected as shown. The drop is shown at *h*, and is of a special design introduced with this type of switchboard.

The drops shown in connection with the standard and series multiple boards, are so constructed that the shutters, upon being rung down, must be restored by hand. This work naturally takes up a large percentage of the operator's time and also necessitates the placing of the drops in such a manner that they shall be within easy reach. In the design of the drop used in connection with bridging boards two points are brought out:

First, the drop being permanently bridged across the line, like the clearing-out drop, must be of high impedance and proof against cross talk. To this end it is wound to a resistance of 600 ohms and is incased in an iron shell.

Second, the drop must be so constructed that it will be restored by the introducing of the plug of the operator's cord circuit either into the multiple or the answering jacks.

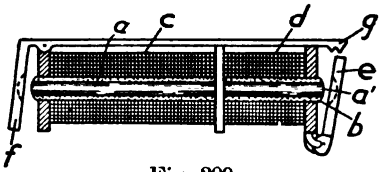


Fig. 209.

To accomplish this, a second coil is wound around the surface of a second core, which, when energized, attracts the armature, which acts as the drop back to its original position. In Fig. 209 is shown this style of drop in section. The cores are shown at *a* and *a′* and are of the usual form, covered with the insulating material *b*. The line coil or that which is bridged to the line, and operates to throw the drop, is shown at *c*. The armature actuated by this coil is shown at *f*, and is pivoted at the top in the usual manner. Attached to this is the stiff wire with the catch *g*. The second armature, which acts as the drop, is shown at *e*, and is pivoted at the bottom. A stop is provided so that it cannot fall through a greater angle than that shown. The second, or restoring coil, is shown at *d*, it being separated from the line coil by a partition. It is wound to have a resistance of about 50 ohms. Both the armatures *e* and *f* have a hollow depression in the center into which fits the end of the core, when they are drawn close up against the magnets. The catch is of a peculiar design, having a notch into which fits the upper edge of the armature *e* when the latter is restored. The smaller projection in the rear of the notch keeps the armature from being attracted any nearer to the core, which would result in its failing to fall by gravity when released. The terminals of the two coils are brought out through holes *f* in the armature.

Fig. 210 shows the general appearance of the drop. Here the armature *f* is shown in the foreground, with the four hard-rubber-bushed holes for the coil terminals. Terminals Nos. 1 and 2 are for the line coil and Nos. 3 and 4 for the restoring coil. The other armature or drop is shown at *e*. The line number is painted on this armature, and an aluminum shutter corresponding in size normally covers it. When the drop is rung down, this shutter swings up exposing the number, and falls into place again when the drop is restored. The drop is mounted on the plate *x*, which separates the two halves. Since these drops need not be placed within reach of the operator they are mounted over the multiple jacks. Turning again to Fig. 208 it will be seen that the section of the drop enclosing the line coil is shown at *i*, while that enclosing the restoring coil is shown at *o*.

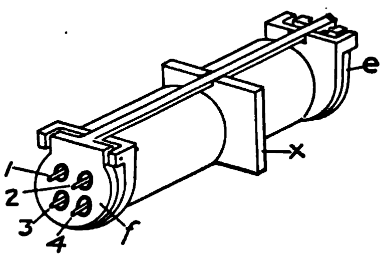


Fig. 210.

Before going into the details of the design of the operator's cord circuits let us consider what would be the effect of introducing the plug into a jack after the drop has been rung down. Let the jack on section I be considered. Plugging into the jack, the tip, to which is connected one side of the talking circuit, makes contact with the spring *c*. The other side of the talking circuit is connected to the shank of the plug, and makes contact with the ring of the jack *e*. The shank is protected with a hard-rubber collar, so that it will not make contact with the outer ring *f*. The plug is so constructed that, when in place, a brass ring makes contact between the springs *d* and *d'*, closing the circuit and allowing current from the battery *n* to flow from one to the other. When this happens, the potential of the battery is thrown on the outer rings of all the jacks for the busy test, and also from the answering jack through the restoring coil of the drop to ground, thus restoring the drop. Analysis of the circuit will show that this action will take place, no matter in what jack the plug is placed.

In Fig. 211 is shown the detail of the wiring of the operator's cord circuit. The tip of the plug is shown at *a*. The brass ring to which no wire is connected, but which serves to close the connection between the two jack springs, is seen at *b*. The shank of the plug is shown at *c* and the two hard-rubber rings insulating *a* from *b* and *b* from *c*, at *f* and *e* respectively. At *d* is seen the hard-rubber collar insulating the shank from the outer ring of the jack. Both plugs are identical. The listening key is shown at *g* and is of peculiar design; it consists of four springs 6, 5, 2, and 7. The springs 2 and 7 are electrically insulated, but mechanically connected by the hard-rubber block *h*. There are three contact

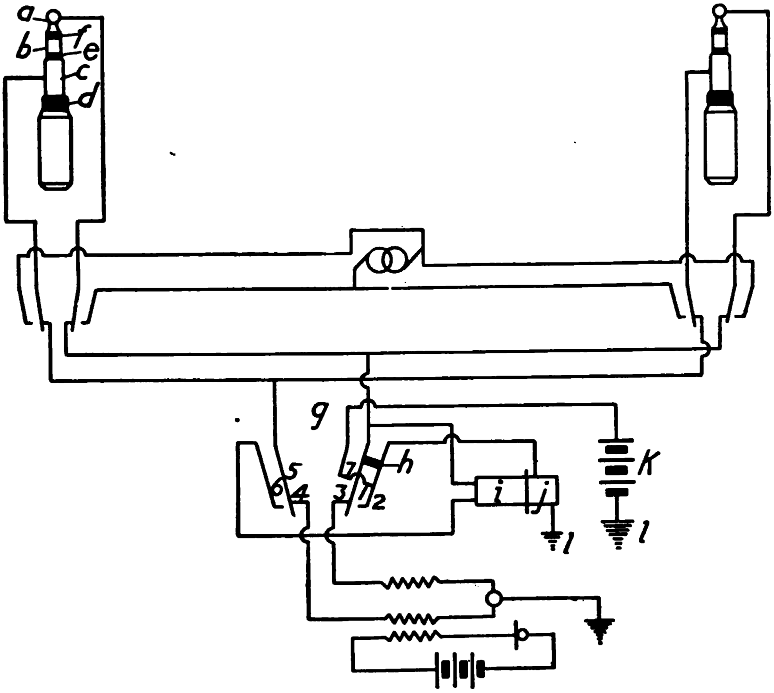


Fig. 211.

points 1, 3, and 4. The springs 5 and 7 are bridged across the cord and the contact points 3 and 4 are connected to the operator's telephone circuit. One terminal of the line coil of the clearing-out drop, shown at *i* is connected to 6, while the other terminal is connected to 7. One terminal of the restoring coil *j* is connected to the spring 2, while the other terminal is grounded at *l*. Grounded battery K, is connected to the contact point *1*.

In the position shown, the operator is able to listen in. Suppose the key depressed, so that contact with the points *1*, *3*, and *4* is broken, and contact made between the springs 5 and 6. The line coil of the clearing-out drop is now bridged across the cord. When, upon completion of the conversation it is rung down, the operator adjusts her key as shown, opening one side of the line coil, cutting in her telephone set, and by closing the contact between the point 1 and the spring 2, throws the current from the battery K through the restoring coil *j*. The clearing-out drop is identical with the line drop in design and construction.

The system just described is an improvement over the series switchboard, because it is perfectly balanced throughout, and the drops are self restoring. It gives excellent satisfaction for local work. The fact that the two line drops and the clearing-out drop are bridged across the line during conversation, tends to reduce the efficiency of transmission. On very long lines this reduction would be serious, and therefore the Long Distance Company cut the drop off by a special form of wiring which will be described later.

Intermediate Distributing Board. It has already been said that the introduction of the bridging board brought into use the intermediate distributing board. It must be remembered that all lines entering a switchboard, are not equally busy. It may happen that the operators on section I find that the lines assigned to them are so busy that the calls can be handled with difficulty, if at all, while those assigned to the operators at section IV are not busy enough to make the operators work up to their full capacity. A remedy that suggests itself as obvious, would be to transfer some of the answering jack circuits from section I to section IV. It must be remembered that in making this transfer, the call number cannot be changed, so that it cannot be made at the main distributing board. What is wanted is to connect that row of multiple jacks to an answering jack and drop placed on section IV. At the intermediate distributing board this change can be readily made by cross-connecting the given multiple wiring to an answering jack and drop placed on the required section.

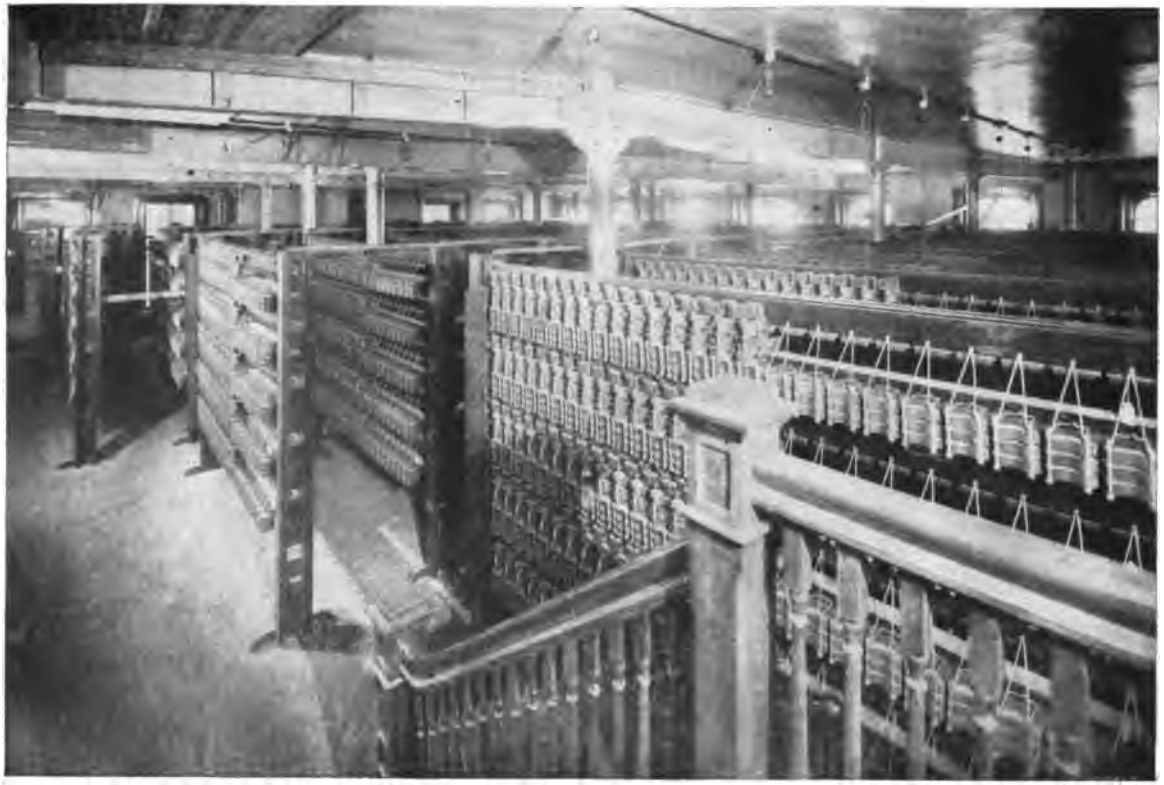
The intermediate distributing board has also another use. Though the growth of the telephone business is steady, subscribers often give up service from one cause or another. From an operating standpoint, it is not good practice to use the call number of the disconnected line for a new subscriber within three months of the date of disconnection. A new connection being established, it is cross-connected to a new set of multiple jacks, but by means of the intermediate board, the old answering jack can be used, and this particular operator retain the same number of lines to handle as she had originally.

In designing, the intermediate frame resembles the main distributing frame, the difference being that no protecting apparatus is used. The multiple-jack wiring is connected to the horizontal side, while the answering-jack wiring is connected to the vertical side. The cross-connecting wire used is triple-conductor twisted wire, two conductors for the talking circuit, and the third for the busy test and restoring battery.

TRUNKING.

The subject of trunking has already been touched on in connection with standard and subdivided multiple boards. It will now be desirable, in connection with full multiple switchboards, to go into the subject rather more in detail. In connection with ring-down trunks nothing additional need be said, as the multiple switchboard introduces no new features, so that the discussion will be given up entirely to circuit trunks. The following points are essential:

In operating with circuit trunks the following events occur in order: The subscriber operator having received a request for a connection necessitating the use of a trunk to a distant exchange, puts herself in communication with the trunk operator at the distant exchange by means of the order circuit, and requests the desired connection; or, to use technical language, *passes the call.* The trunk operator, having received the call, assigns the trunk to be used and after testing the subscriber line called for and finding it not in use, plugs into it with the trunk plug. This interval is called *that required to put up the connection.*



SWITCHBOARD OF AUTOMATIC EXCHANGE OF TELEPHONE DEPARTMENT, CHICAGO SUBWAY CO.

Automatic Electric Co.

Upon the completion of the conversation, the subscriber operator at the first exchange withdraws the plug from the answering jack, and again going in on the order circuit orders the trunk operator at the distant exchange to withdraw the trunk plug from the called subscriber's multiple jack or to *clear the trunk* as it is called. The trunk operator thereupon does as directed. The interval from the time that the conversation is finished and the ring-off signal given, up to the time that the trunk is cleared, is called the *time required to clear the connection.* The first interval is shorter than the second and is almost a minimum; there is no possible way in which its length can be materially reduced.

The history of trunk development is connected with the development of the switchboard, so that the trunks first considered will be those between two exchanges equipped with series boards.

In order that the trunk operator may have no other class of business to handle, the trunk plugs are placed together at one end of the switchboard. The number of sections thus occupied will depend altogether on the number of trunks handled. In Fig. 212 is shown the wiring of a circuit trunk between two series switchboards. One exchange is shown at B and the other at A. The multiple jacks are shown at 1, 2, 3, 4, and 5; one jack within reach of each operator. The trunk jacks are placed in a group separate from those on the subscriber lines, and are called *the outgoing trunk multiple.* In general, trunks used for completing connections from an exchange B to another exchange A are called, with reference to B, outgoing or sending trunks; while those used for completing connections from another exchange are called *incoming trunks.* Thus the trunk shown in Fig. 212 with reference to B is an outgoing trunk, and with reference to A, an incoming trunk. The plug in which the trunk ends at the incoming extremity is shown at *f* and is of the same type as that used on the subscriber's cord circuit. At *s* and *p* are shown the secondary and

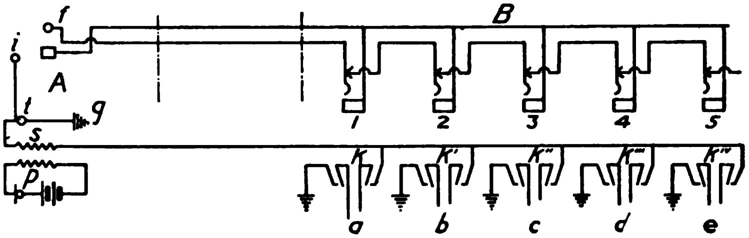


Fig. 212.

primary windings of the trunk operator's induction coil, while the head telephone is seen at *t*, one terminal of the coil being grounded at *g*. For the opposite terminal of the receiver, runs a single conductor cord which terminates in a plug *i*. The order wire is a grounded circuit running from the trunk operator's head receiver to one of the outer springs on each one of the order wire keys K, K^{I}, K^{II}, etc. The other outside spring of these keys is grounded; the two inner springs of each key are wired to the subscriber operator's telephone circuit as shown in Fig. 203, and at *a*, *b*, *c*, etc., in Fig. 212. The order wire is thus a grounded circuit.

It should be observed at the outset that the trunk operator cannot communicate to the subscriber operator, unless the latter has his key depressed. Suppose a call comes in at the exchange B for a party whose line terminates at A, and that it is answered by the operator stationed at the jack 5. This operator after learning the subscriber's wish depresses the order key K^{IV} and transmits the call to the trunk operator at A. Before the latter puts up the connection, she must ascertain whether or not the subscriber line called for is busy. To do so she touches the ring of his multiple jack with the tip of the single plug *i*. As she does this she calls back to the subscriber operator at B the number of the trunk that she is going to use, the latter operator waiting with the key depressed for the receipt of this information.

Assuming that the line called for is not busy, the trunk operator plugs into it, and the subscriber operator at B rings. As has already been stated, the trunk operator is altogether unable to listen in on the connection, and must depend on the order coming over the order circuit as to when the trunk shall be cleared. The conversation being completed, and the ring-off being received by the subscriber operator, she again goes in on the order circuit and directs the trunk operator to clear the trunk.

While this method seems very simple, and while it seems that the trunk operator should be just as diligent in clearing connections as she is putting them up, such is not the case. It must be remembered that at the instant when the subscriber operator comes in to order down a connection, another may come in to order one up. In fact, two or more operators may order up connections at the same instant. In such a case, the trunk operator will always pay more attention to orders to make connections than to those to clear. So that the trunk operator often puts off clearing a connection until she has forgotten about it. In the meantime, the subscriber operator at B, has cleared that end of the connection so that the called-for subscriber is left connected to the trunk without any means of signaling either one of the exchanges.

This condition has two results: *First*, the called subscriber cannot signal the exchange to get a connection, and, *second*, nobody can call him because the trunk plug being in his jack, his line will be reported busy. All this necessitates a second request from the subscriber operator to clear the trunk, which multiplies the work done over the order wire, which tends to confuse the trunk operator and delay her work.

It was found also that a grounded order wire was liable to become noisy, causing the transmission to become poor, and necessitating the repetition of orders over it, to the further detriment of the service. Two changes were made in the wiring, which are shown in Fig. 213. The first was to use a metallic order circuit as shown, the busy test being obtained for the trunk operator through her split receiver to ground at *g*. The second change consisted of wiring a drop *a* to the trunk at the outgoing end. This was called the *safety drop*, and its use was calculated to prevent the called subscriber from being "hung up" on the trunk, by affording him a means of signaling in. This drop was wired in the usual manner, so that when the outgoing end of the trunk was taken up it was cut off.

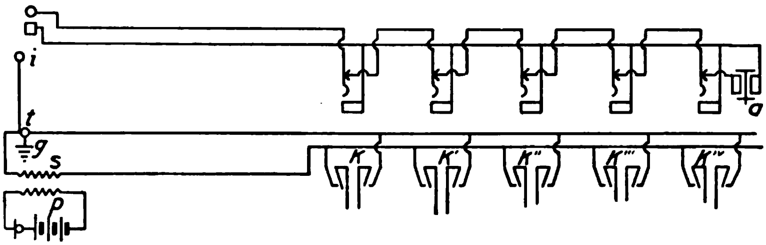


Fig. 213.

The method of the operation was as follows: The subscribers having rung off and the connection having been cleared at the outgoing office, if the trunk operator fails to clear the connection, the called subscriber, upon ringing, will throw the safety drop, thereby attracting an operator's attention. This operator will plug into the trunk jack, learn the subscriber's wish, and going in on the order circuit again, order the trunk operator to clear the connection.

While the scheme prevented the called subscriber from being indefinitely hung up, it did not reduce the work over the order circuit, nor help out the trunk operator. To this latter end, a practice was introduced about this time called *testing down.* It worked as follows: Inspection of the operator cord circuit shown in Fig. 207 reveals the fact that there is a battery on the shank of both plugs. Now when one of these plugs is placed into the trunk jack, this battery being thrown on the ring, current flows along one side of the trunk to the shank of the plug at the other office. Therefore, if the trunk operator touches the shank of the plug with the test plug *i*, a click will be heard in her receiver, due to this current flowing to ground through the split receiver. This "test" will be heard so long as the subscriber operator has a plug in the trunk jack. Upon her clearing the connection, however, the current will be received and the test will disappear.

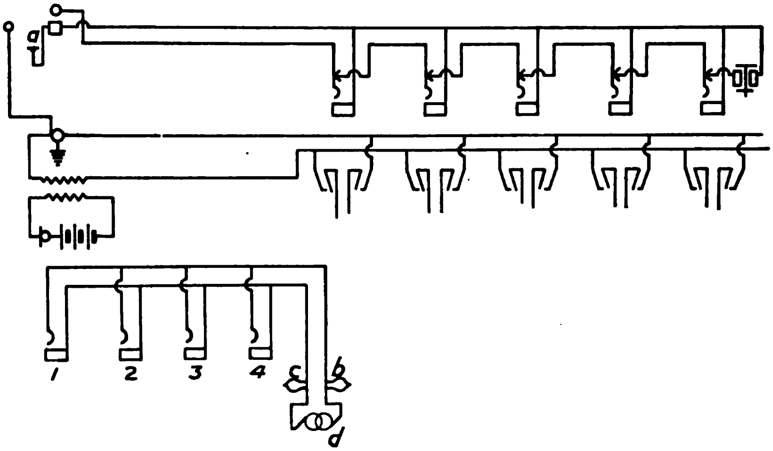


Fig. 214.

To facilitate the clearing of trunk connections, the trunk operator was required to touch, from time to time, the shanks of the trunk plugs upon connections, with the test plug, and to clear all that did not give the test. It being assumed that if the subscriber operator had removed her plug, that the conversation was completed. While this scheme, together with the safety drop, reduced the chances of a subscriber being hung up, and therefore increased the efficiency of the trunks, it did not lessen the work of the trunk operator. In fact, it increased it, as she was compelled to be continually, when not otherwise occupied, reaching over the face of the board to test the trunk plugs. To overcome this difficulty, *test buttons* were introduced. These consisted of brass buttons about the size of a copper cent, placed on the plug shelf, each one directly in front of the plug to which it is wired. One of these is shown at *a*, Fig. 214. To test down, the operator need only touch these buttons, which saved her the time and trouble of reaching all through the multiple, wherever the plugs happened to be.

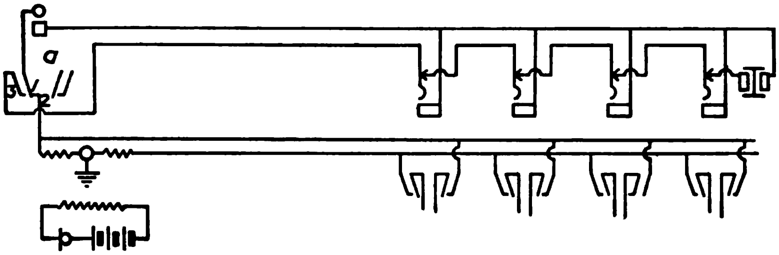


Fig. 215.

So far, the condition of the called-for subscriber's line being busy has not been considered. With the circuits heretofore described, if this condition obtained, the trunk operator would have to wait till the subscriber operator again came in on the circuit before she could be informed of the fact. To save this delay, the *busy-back* was devised. It consists of a series of jacks placed within reach of all trunk operators, and shown at 1, 2, 3, and 4. To these jacks is wired a small alternating-current machine shown at *d*, giving a potential of 75 volts and having two lamps *b* and *c* in series, to reduce the current to the proper amount. If the trunk operator finds the line called for to be busy, she plugs the trunk into the nearest of the busy-back jacks. The subscriber operator plugging into the trunks, hears the hum of the alternator, and knowing what is meant, reports *busy* to the calling subscriber.

In order to test the subscriber's lines, the trunk operator had to make use of a third plug as has been shown. Now, the trunk operator is often busy with both hands, so that to carry a test plug was a source of great inconvenience, and a material hindrance to her work. To overcome this defect, the trunks were so wired that the testing could be done with the trunk plug, as shown in Fig. 215. The tip side of the trunk plug is wired to the middle spring of a key *a*. The same side of the trunk, coming from the other exchange, is connected to the outer spring 3 of the same key, and the inner contact point 2, to the operator's induction coil. With the key in the position shown, the test can be obtained through the tip of the plug. When the plug is placed in the jack, the key is depressed, cutting off the circuit through the operator's receiver, and closing the trunk through the springs 1 and 3 of the key.

This circuit represents the highest development of trunking between series switchboards.

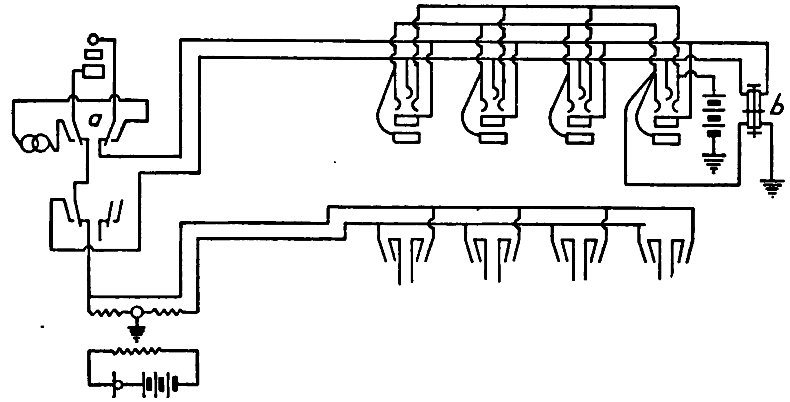


Fig. 216.

With the introduction of the bridging board, there came a necessary change in the wiring of the trunks. Fig. 216 shows the earliest form of trunk used with this system. It is wired at the outgoing end in the same manner as the subscriber line, the safety drop *b* taking the place of the line drop. This drop is slightly different in action from that used with the series board. Here, when the subscriber operator plugs into the trunk, current is sent through the restoring coil and the drop is sealed. Upon being cleared at the sending end, however, this current is removed, and the drop is free to be rung down. With this system, since no battery is connected to the shank of the subscriber operator's cord circuits, the scheme of testing down cannot be resorted to. It will be observed that a ringing key *a* is wired to the trunk cord, to enable the trunk operator to ring the called subscriber.

In order to do away with the necessity of ordering the trunk to be cleared over the order wire, upon completion of the conversation, a scheme was brought out in connection with this form of trunk. It consisted of a *disconnect signal*, placed at the incoming end, and so wired that it would give notice to the trunk operator automatically, upon the connection being taken down by the subscriber operator.

The wiring of this signal, as first introduced, is shown in Fig. 217. Here, the springs on the opposite side of the testing key are used. The outer, No. 2, is wired to one side of the trunk, while the middle one, No. 1, is wired to one terminal of the coil of a relay, shown at *a*, the other terminal being permanently connected to the opposite side of the line. This relay consists of an electromagnet of high impedance, with a pivoted armature *c*, which, when the relay is energized, is drawn up against a contact point *d*. Since this relay is permanently bridged across the trunk, and since several are likely to be mounted together, each one is encased in an iron shell to

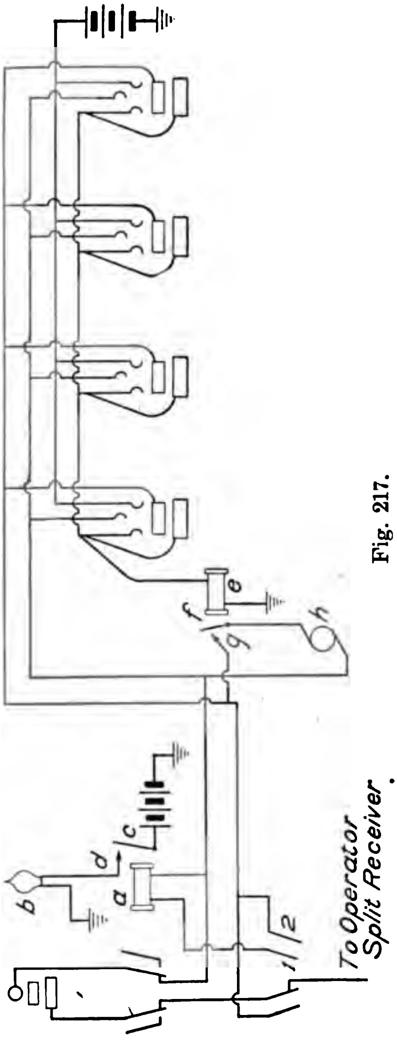


Fig. 217.

prevent cross talk. Wired to the armature of this relay is a battery, and to the contact point is connected a small lamp *b*, the other terminal of which is grounded. At the outgoing end is another relay *e*, which is similar in construction to the restoring end of a bridging drop. The armature *f*, to which is connected one terminal of a small 20-volt direct-current generator *h*, rests normally against the contact point *g*, which is permanently connected to one side of the line.

The method of using this trunk is as follows: When the trunk operator plugs into the subscriber jack, and adjusts the key to cut off the test, the relay *a* is bridged across the line through the springs 1 and 2. The current from the direct-current machine *h* flows out over the trunk, through the armature *f* and the contact *g*, and energizes the relay *a*. Its armature *c*, being drawn up against the contact *d*, closes the battery circuit through the lamp, with the result that it is illuminated.

Upon the subscriber operator plugging into the trunk jack, current is sent through the relay *e* and as a result the armature is drawn away from the contact *g*, cutting off the current from the machine *h*. This current failing, *a* ceases to be energized, its armature *c* falls away from the contact *d*, and the lamp *b* is extinguished. At the completion of the conversation, the subscriber operator removes the plug from the trunk jack, with the result that current is cut off from the relay *e*, whose armature therefore falls against *g*, thereby again cutting the current from *h* on the trunk. The relay *a*, therefore, again becomes energized, the lamp circuit closed, and the lamp lighted. The trunk operator, upon seeing the illumination, instantly clears the trunk without waiting for further orders.

This device is by far the most useful ever invented for expediting the work of the trunk operator. By doing away with the necessity of ordering down connections, half the business was removed from the order wires, so that orders for connections could be transmitted with much greater dispatch and clearness, and the trunk operators having only orders to establish connections transmitted to them could listen with undivided attention, and therefore do better work.

One more change was necessary to bring the trunk up to perfection, as far as it could be obtained with the bridging-board system, and that was to save the trunk operator the time taken to adjust the testing key. This was accomplished by placing a relay on the trunk, the contacts of which would do automatically what those of the manual key did. The wiring of this trunk is shown in Fig. 218. The manual key is replaced by a relay *a* which is wired to the brass ring of the trunk plug so that when it is pushed into the jack on the subscriber line, the current used for the busy test also flows through the coil of the relay, causing it to be energized. The armature of this relay actuates two springs *b* and *c*, to which it is rigidily attached. The armature is insulated from the two springs, and the two springs are insulated from one another. The relay is equipped with two inner contact points, 2 and 3, and two outer ones, 1 and 4, so that in action it is identical with the manual key. The circuit passing through the operator's receiver to give her the busy test, is wired to contact 1, and the tip of the trunk plug, to the spring *c*. One terminal of the coil of the relay actuating the signal lamp, is connected to contact 3. The spring *b* is wired to the opposite side of the trunk and contact 4 is spare.

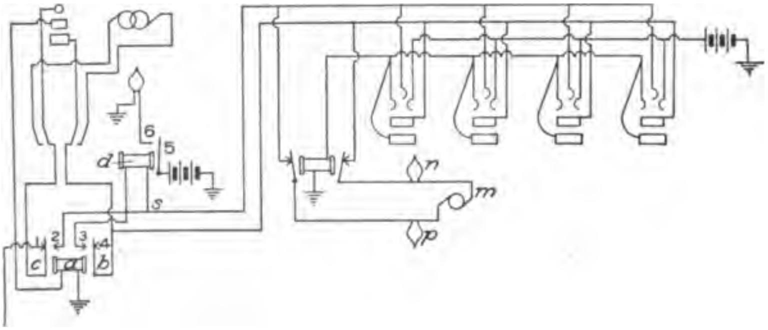


Fig. 218.

The other terminal of relay *d* is wired to the trunk at *s*. When the relay *a* is energized, the springs *c* and *b* are drawn away from the contacts 1 and 4 respectively, and brought up against contacts 2 and 3.

At the outgoing end, the trunk is wired in the same manner as that previously shown, except that the direct-current generator *m* gives a potential of 75 volts instead of 20, and two lamps *p* and *n* are used for reducing the current to the amount requisite to operate the relay *d*, which is about .08 ampere.

It was found more convenient to use a higher potential, for by using lamps of proper resistance the system could be made to work on trunks varying greatly in length. The necessary resistance of the lamps will depend altogether on the resistance of the trunk on which they are used.

The operation of this trunk is the same as that previously described. When the trunk plug is pushed into the subscriber jack, the relay *a* is energized and contacts are made between *c* and 2, and *b* and 3, so that the tip side of the trunk is cut through, and the relay *d* bridged across. Current from the generator *m* energizes *d*, closing the lamp circuit and lighting the lamp. When the subscriber operator plugs into the trunk, the relay at that end is energized, cutting off the current from the machine, causing *d* to " release ", thereby putting out the lamp. Upon the subscriber operator clearing out, current from the machine *m* is again cut in, *d* is again energized, lighting the lamp, thus signaling the operator to clear out.

AUXILIARY APPARATUS.

The auxiliary apparatus used in a telephone exchange can be classed under two headings. First, *Power Apparatus;* second, *Protection Apparatus.*

Power Apparatus. There are two kinds of power apparatus used: Dynamos or Dynamotors, and Batteries. Two classes of dynamos are used—direct and alternating. The first-named type is employed to charge the storage batteries, and for operating the lamp signal on the trunks. The second type is provided to finish the ringing current and that for the busy-back jacks. The nature and size of the ringing-current machine depend upon the size of the exchange and the volume of business handled. In small exchanges equipped with two or three standard boards, and in which the number of calls handled is not as great as to require the operator to put forth her utmost efforts, hand generators, similar to those used in telephone instruments, are employed. They are placed in the keyboard with the handle projecting through the front of the trough, one being provided for each section. Where the number of sections is in excess of three, or where the business is heavy, some form of power generator must be installed. Where water power is available, the usual practice is to use a water motor belted to a small but powerful magneto generator; if there is no water power, a small electric motor is used, to which the generator is belted.

One type of magneto generator is shown in Fig. 219. It is of the same general make-up as that used in the subscriber telephone. It is larger and more powerful, and differs in a few details:

It consists of five permanent magnets bolted to two pole pieces. One terminal of the armature coil is connected to an insulated collar *s* on the shaft, the other is connected to the shaft. There are two copper brushes, one bears on *s* and the other on the shaft, from the two terminals *a* and *b*. Two oil cups *c* and *d* are provided for lubricating the bearings. The opposite end of the shaft is equipped with a pulley *e*, over which is placed the belt. The flat pulley is often replaced with a grooved one, for the accommodation of a cylindrical belt. The whole machine is mounted on a wooden base, upon which are placed the two line binding posts *m* and *m'*. The armature of this type of the machine is wound to give a potential of from 75 to 80 volts.

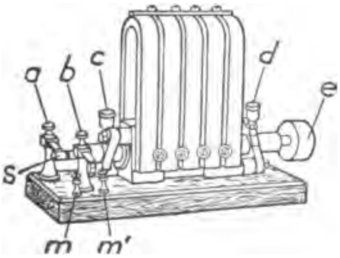


Fig. 219.

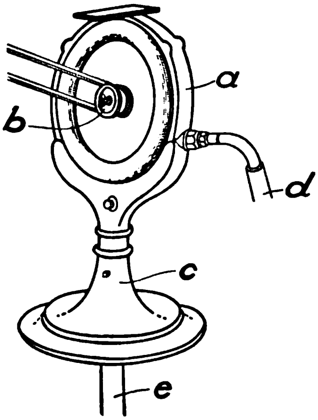


Fig. 220.

In Fig. 220 is shown a very compact and convenient form of water motor for use in small exchanges. It consists of a turbine encased in an iron chamber *a*. To the shaft is attached a pulley *b*, the whole being supported on a stand *c*, through the center of which passes the discharge pipe *e*. The supply pipe is shown at *d*. This supply pipe terminates inside of the motor in a nozzle about $\frac{1}{16}$ inch in diameter, through which the water is forced, to impinge against the buckets of the wheel.

The discharge pipe should have a diameter of about 1½ inches and should run straight for a distance of 20 feet from the motor. This type of machine can be used successfully in localities where the water pressure is at least 40 pounds per square inch. It runs noiselessly and requires very little attention.

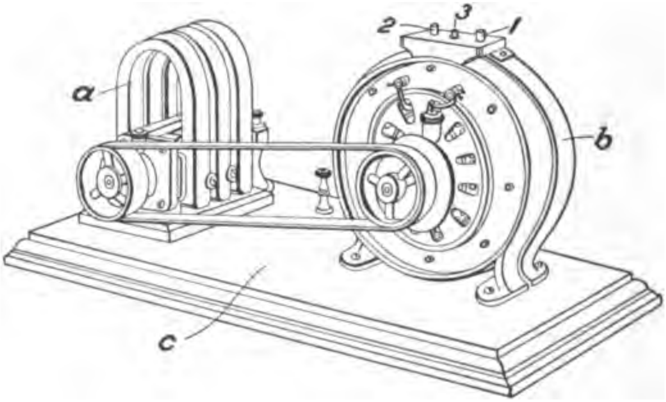


Fig. 221. .

In Fig. 221 is shown one of the most approved types of induction motors used for operating magneto generators. The motor is shown at *b*. It is of the usual type of induction motor made to operate on single-phase alternating circuits. It is made self-starting by dividing the stator winding into two halves, one of which has a choke coil in series with it, and the other a non-inductive resistance. A push button 3 mounted on top of the case, serves to make the necessary connections when starting, by simply depressing it. The terminals are shown at 1 and 2.

The magneto generator is shown at *a* and is mounted, together with the motor, on the same wooden base *c*. This unit gives very good results and is used very extensively.

Even when some form of power generator is used in smaller exchanges, hand generators are supplied to be used in the case of the failure of the former. In larger exchanges, motor generators are used, and the motor end is wound for direct or alternating current as the case may require. In Fig. 222 is shown a motor generator used for charging storage batteries. It is built by the Crocker-Wheeler Co. and is self-contained and very compact. The motor end (which in this case is direct current) is shown in the foreground, and the dynamo end, in the background. The base of the machine forms the yoke, upon which are mounted the field coils. The pole pieces are at the top, one being shown at A. The starter is shown mounted on the side of the pole piece, and is controlled by the handle H, which actuates a contact moving between four upright clips. The motor side is wound to the potential of the mains on which it is to operate, and the dynamo side delivers current at a potential slightly in excess of that of the battery it is to charge.

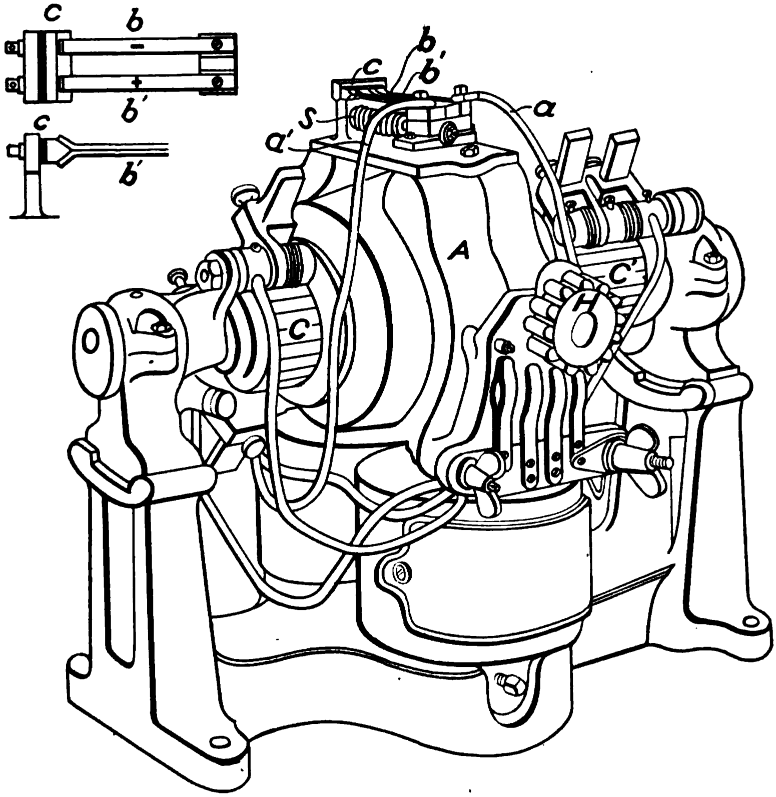


Fig. 222.

One very important point about a charging dynamo is that it should have an automatic cut-out, which opens the circuit, when the current delivered by the dynamo falls below a certain fixed amount. This is to prevent the battery from discharging through the armature should the motor slow down or stop from failure of the current supply in the mains. A very ingenious form of cut-out is used in this type of machine. It is mounted on top of the pole pieces. The front pole piece A is hinged so as to swing out, and is held in place by the attractive force of the magnetic field. A spiral spring S is securely fastened to the back pole piece and rests against a block on the front one. When the strength of the magnetic field is of the proper amount, the tension of this spring is overcome and the pole piece held in place. When the field is in place, two brass clips *b* and *b′* close the circuit to the battery, which is carried by the leads *a a′* through the back brass block *c*. Should the field weaken sufficiently, so that the dynamo is unable to develop a potential sufficiently high to feed the batteries, the tension of the spring will then overcome the attractive force, A will be swung forward, and the circuit to the battery through the clips broken.

Ringing-current machines are built according to the design shown, only there is no automatic cut-out present, and the dynamo side is wound for alternating current at a potential of 75 volts. The two commutators are shown at C and C′.

Batteries. Two types of batteries are used in telephone exchange work: Primary and Secondary or Storage. The choice between the two depends altogether upon the amount of current needed, the cost of charging, and the cost of the electrolyte and elements in the case of the primary cell. In general, in small exchanges, consisting of three sections of standard board or less, primary cells are used, while in larger exchanges, storage cells find favor.

Of the various types of primary batteries, either gravity or Fuller cells are used. The maintenance of the former type is less than that of the latter; but, on the other hand, the cost of the former is greater than that of the latter. So that where a great number of cells are needed, the Fuller batteries are used, and when a small number are required the gravity cell comes into play. Three gravity cells in series are placed on each operator's transmitter circuit, while two Fuller cells are usually deemed sufficient. The wire used for battery leads is No. 14 B. & S. gauge soft-drawn copper with rubber insulation protected by heavy braid. The conductors of a pair are twisted together, so that a number of leads may be sewed up together in cable form without producing cross-talk.

Mr. J. J. Carty, Chief Engineer of the New York Telephone Company, conceived the idea of feeding a bank of transmitters from one storage battery. He realized that on account of the exceedingly low internal resistance of this type of cell, no cross-talk would be produced by so doing. The reason was as follows: After two or more transmitters, each taking normally .20 amperes, be connected to the same battery, the fluctuation in the internal fall of potential due to the fluctuations in the current furnished to one transmitter upon its being talked into, is of infinitesimal amount owing to the very low internal resistance, so that the other transmitters are furnished with a steady current. This condition would be impossible with any form of primary cell. Two cells are required in series, and the number of elements in each will depend upon the number of transmitters to be fed.

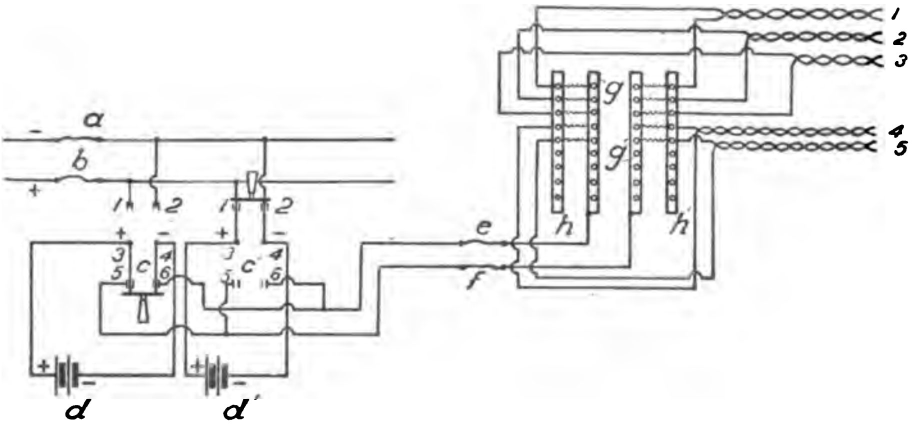


Fig. 223.

Fig. 223 shows the method of connecting up the batteries. The mains coming from the charging machine pass through two fuses *a* and *b*, and thence to two knife switches *c* and *c'*. Each of these switches is equipped with three pairs of contacts 1, 2, 3, 4, 5, and 6. The switch is pivoted to 3 and 4. The charging leads are wired to 1 and 2, and the battery leads to 3 and 4. The transmitter leads are connected to 5 and 6.

The switch *c'* is thrown into the position to charge the battery *d'*, the current passing from the contacts 1 to 3, and 2 to 4 through the battery, the transmitter leads being at 5 and 6. The switch *c* is thrown into the position to discharge the battery *d* into the transmitters, the current passing through the contacts 3 and 4 to 5 and 6 and thence to the transmitter bus-bars *g* and *g'*. The charging leads are open at 1 and 2. The transmitter leads are fused at *e* and *f*. The bus-bars are made of copper rods, drilled and tapped for machine screws to hold the fuses for the various transmitter circuits. The wooden strips *h* and *h'* are placed on opposite sides of the bus-bars, equipped with binding posts for the accommodation of the fuses and the transmitter wires, the latter being shown at 1, 2, 3, 4, and 5.

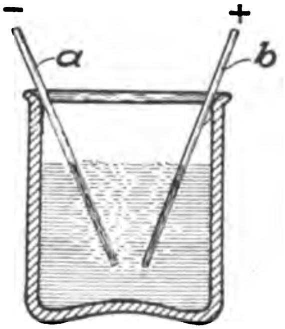


Fig. 224.

In connecting up the charging leads, the utmost precaution must be taken to properly adjust the polarity, so that the positive lead of the charging circuit will be connected to the positive pole of the battery. A very convenient method of finding the positive pole of the charging circuit is to dip the two terminals in a jar containing water made slightly acid or water into which has been thrown a pinch of salt. This point is illustrated in Fig. 224 at *a* and *b*. Upon so doing, bubbles will be seen to rise from the two leads, but much faster from one than the other. The one from which they rise the faster is the negative lead. This experiment is rather dangerous and should be performed with great care.

Another simple method, and one not attended with so much danger, is to allow current to flow through the leads while an ordinary compass is held under one of them. The point to remember is that when a current flows over a magnetic needle from north to south, the north pole of the needle is deflected to the east.

The success of the scheme of feeding a bank of transmitters from a storage battery rests on the fact that the resistance of the leads to the bus-bars must be as small as possible. Therefore great care must be taken to make the leads as short as possible, and of sufficiently heavy wire. In general, it might be said that the battery should have a capacity of 50 amperes for small exchanges, and the total resistance, including the battery to the bus-bars, should not be over .006 ohm. A great deal of troublesome cross-talk has been caused by overlooking this fact, in exchanges that are otherwise installed with the utmost care; and unless one is familiar with this point, such cross-talk is very difficult to locate.

Protection Apparatus. This subject has already been touched on in connection with the main distributing board. It will now be necessary to go into it a little more in detail in connection with power wiring. Reference to Fig. 223 will show that fuses are placed in the charging circuit, and in the discharge circuit to the bus-bars, and on each individual transmitter lead. The best plan to follow in exchange wiring is to place the necessary knife switches, fuses, bus-bars, etc., on a slate power switchboard, upon which are mounted also an ammeter in the charging circuit, a voltmeter on the same circuit, and also one to measure the potential of the battery. In Fig. 225 is shown the style of fuses used on the charging and discharging mains. It consists of a strap of fuse metal *c* attached at either end to two copper lugs *a* and *b*. These copper lugs are slotted to fit over studs, and are held in place by nuts. The fuse metal is made of the requisite size to carry the current required. The type of fuse used on the leads to the transmitter bus-bars is shown in Fig. 226, and consists of a hollow cylindrical fiber tube *a* fastened to two German-silver slips *d* and *e*, by two brass screws *b* and *c*. Through the center of the tube runs the fuse which is soldered at each end to the brass collars *m n*. The lugs are fastened to the power board by means of the screws *s s'*.

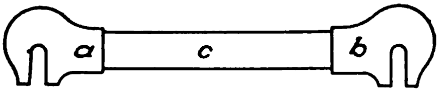


Fig. 225.

Switchboard Construction. Fig. 227 shows the rear view of the multiple switchboard, in which will be seen the construction of the framework and the placing of the cable and the wiring. At A and B are shown the multiple cables for the subscribers' lines and the outgoing trunks. It will be seen that they rest upon a shelf running along the length of the board. The five bottom rows are for the outgoing trunks, and the remainder are for the subscriber lines. Running in a trough at C, are seen the answering jack cables which turn up at their respective sections; they are formed out and take the answering jacks at D, D', and D''. Just below these forms is seen the wiring of the operator's circuits.

It should be noticed that these switchboards are built in sections, each accommodating 3 operators. This is the usual construction. Every multiple jack is within reach of every operator; the operator sitting in the center position, can reach everything on her own section, while the operators occupying the end positions, can reach on the adjacent sections everything that is inaccessible on their own.

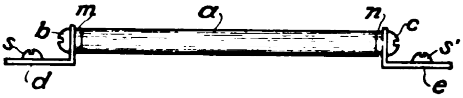


Fig. 226.

COMMON BATTERY SYSTEM.

The desire to centralize power has permeated even the telephone practice, and within the past five or six years various systems have been introduced with this end in view. It was supposed that if the batteries could be removed from the subscriber telephones, the cost of their maintenance would be entirely wiped out. If the batteries were all concentrated in the exchange, and the current fed out over the line during conversation, they could be maintained in better shape and at a lower cost than when scattered about the district at each subscriber station. Again, the current may be used for automatic signals which would accelerate the service. These considerations led to the development of the so-called *common battery*, or *central energy* systems that have come rapidly to the front in the past three years.

The earliest and simplest method for using a common battery is shown in Fig. 228. In this case, the receiver and transmitter of both subscriber instruments are connected in series with the battery *a* in the middle. Grounded circuits are used. This method of connecting up telephones is known as *direct transmission* and operates as follows: Let the right-hand telephone be used for transmitting and the left-hand one for receiving. The transmitter *e* upon being spoken into will cause a variable current to flow over the line, and this passing through the receiver *b* will reproduce the sound in the usual manner. Transmission is carried on in the opposite direction in the same manner.

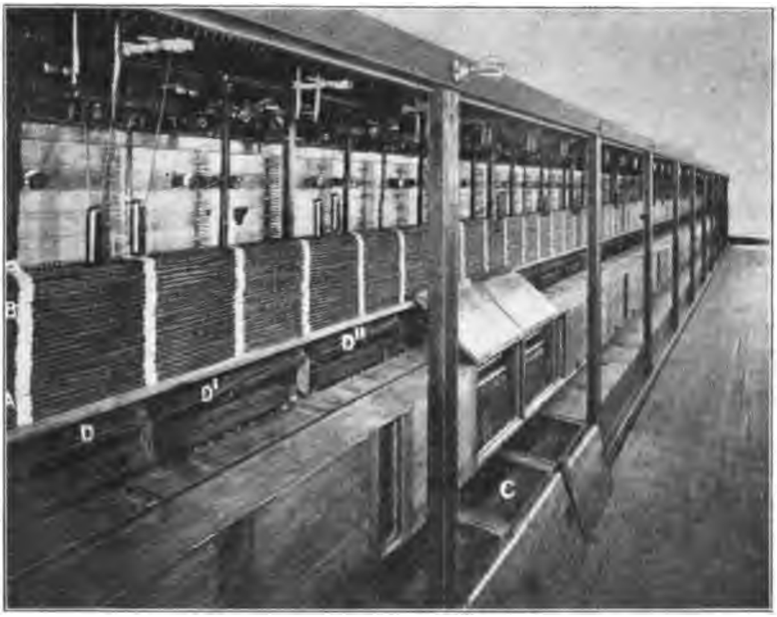


Fig. 227.

As has already been pointed out, this direct transmission is not sensitive, because the resistance of the line forms too great a ratio to that of the transmitter. For short lines it does very well, but for general use it does not give good results. The operator's cord circuits have each an independent battery so that cross-talk may not result.

The Stone System. Probably the first system devised whereby one common battery was made to feed all the cord circuits was that devised by Stone. The plan of wiring is shown in Fig. 229 where *a* and *b* represent the receiver and transmitter at one station, and *c* and *d* those at the other. The battery *g* is connected across the line through the retardation coils *e* and *f*. A metallic circuit is used throughout. The action of this system is as follows:

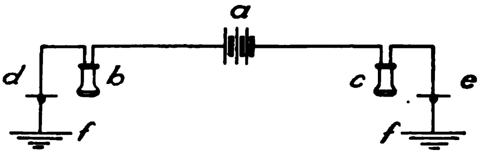


Fig. 228.

Current flows from the positive pole of the battery *g* through the retardation coil *e* to the point *o* where it splits, one portion going through the receiver *a* and transmitter *b* back to *o'*; the other portion flowing from *o* through the receiver *c* and the transmitter *d* goes back to *o'*. This current divides itself in proportion to the resistance of the two circuits. The retardation coils *e* and *f* are wound with comparatively heavy wire, so that while the ohmic resistance is low the impedance is very high. As a result they offer very little resistance to the flow of the direct current of the battery, but entirely choke out the rapidly varying current produced by talking.

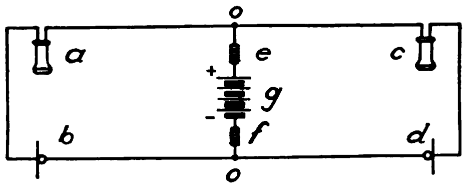


Fig. 229.

Since the current in the two branches divides itself in the inverse ratio of the resistance of the two circuits, the flow of current through the retardation coils is practically constant. The talking current flows around the circuit through the two receivers and transmitters. On short lines this system works well, giving better results than the one previously described.

It has been said that this system renders it possible to use one common battery for all the cord circuits, and that with the use of the retardation coils cross-talk is done away with. The method in which this is accomplished is shown in Fig. 230, in which two connections each between two subscriber lines are shown. At *a* and *b* are shown the two retardation coils on one pair of cord circuits, and at *c* and *d* those on the other. To illustrate this action, let us suppose that conversation is being carried on over the other connection. As the transmitters are talked into, a variable current flows out from the battery over the circuit. It might seem at first sight that this current upon reaching the points 1 and 2 would divide, part flowing through the lower connection. This is prevented by the retardation coils in the following manner:

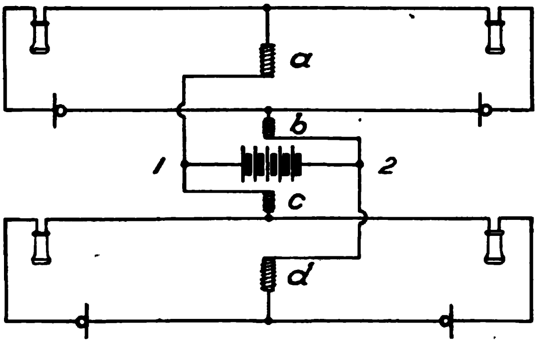


Fig. 230.

First, it has been shown that the variable talking current is nearly all confined to the circuits joining the two subscriber telephones, and that the current flow through the retardation coils is nearly obstructed. Whatever variable current does pass through these two coils would, upon reaching the points 1 and 2, have two paths, the one through the retardation coils *c* and *d*, and the other through the battery. The first possesses high induction, the second almost none, so that this variable current would all flow through the battery, thus preventing cross-talk.

Hayes System. A modification of this system, gotten out by Mr. Hammond V. Hayes, is shown in Fig. 231. Here the retardation coils of the Stone system are replaced by a repeating coil having four windings *a*, *b*, *c*, and *d*. Suppose that station

No. 1 is transmitting to station No. 2, a variable current will be set up through this station which will pass through the windings *a* and *c* of the repeating coil. In consequence, an alternating current will be induced in the windings *b* and *d* of the coil, which will flow through station No. 2, reproducing the sound.

Should station 2 wish to transmit to station 1 by talking into the transmitter a variable current is set up through the windings *b* and *d* of the repeating coil, with the result that induced currents are set up in the windings *a* and *c*, which reproduce the sound at the other end. The repeating coil thus acts as an induction coil. When station 1 transmits to station 2, the windings *a* and *c* are the primary, and *b* and *d* the secondary. When transmission is carried on the other way the reverse is the case.

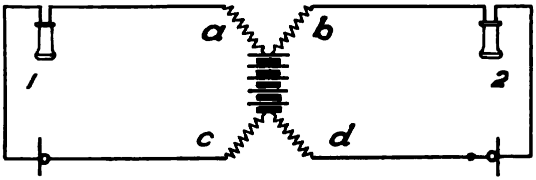


Fig. 231.

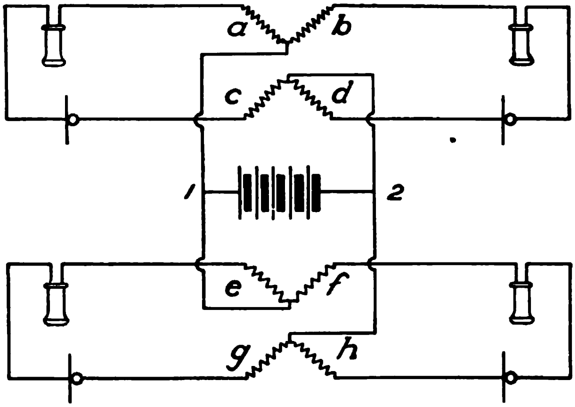


Fig. 232.

With this system, as with the one previously described, a common battery is used on all the cord circuits, and cross-talk is kept out in much the same manner. This point will be illustrated by reference to Fig. 232, in which two connections are again shown. If conversation is being carried on over the upper connection, the variable current, through what happens to be the primary winding, and the induced current, through what happens to be the secondary winding, upon reaching the points 1 and 2, have a choice of two paths, one through the battery and the other through the retardation coils in the lower circuit. The battery, however, having practically no self-induction, prevents any of this current from reaching the lower circuit and producing cross-talk. This system gave better results than that invented by Stone, because the current from the battery is used only to feed the transmitter, the repeating coil in the exchange acting like an induction coil. In other words, it is one step removed from direct transmission.

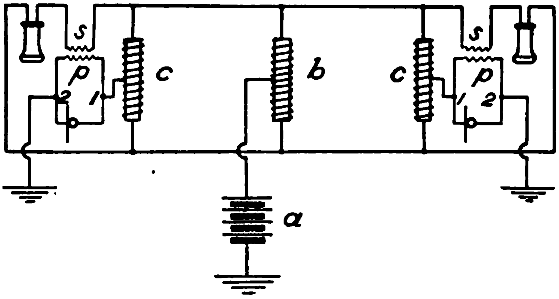


Fig. 233.

The next step in the development of this system was to place an induction coil in each of the subscriber telephones, and to this end the Dean system was introduced. The plan of wiring is shown in Fig. 233. A grounded battery *a* is connected to the center point of a retardation coil *b* which is bridged across the line. A second retardation coil *c* is placed at each subscriber station and from its center a connection is made to point No. 1 in the transmitter circuit of the telephone. Point No. 2 at the opposite side of this circuit is grounded. The current from the battery, upon reaching the middle point of the retardation coil *b*, splits, one half following one side of the line and the other half following the other side. Upon reaching the subscriber station, these two halves flow through the retardation coil *c*, uniting at the middle point and flowing to point No. 1. Here the current again divides, one half going through the primary winding of an induction coil, and the other half passing through the transmitter. They again unite at 2 and flow to ground.

It should be observed that the arrangement of the transmitter circuit is somewhat different from anything yet shown. Instead of the current flowing through the primary coil and transmitter in series, the one is shunted onto the other, which gives a more sensitive arrangement. The transmitter current flowing out over both sides of the line in parallel has no inductive effect, providing the resistances of the two sides of the circuit are equal. The talking current, induced in the secondary winding of the induction coil, flows over the line in the usual way, and on account of the high self induction, does not pass through the retardation coils. As far as transmission is concerned this is a better arrangement than any previously described.

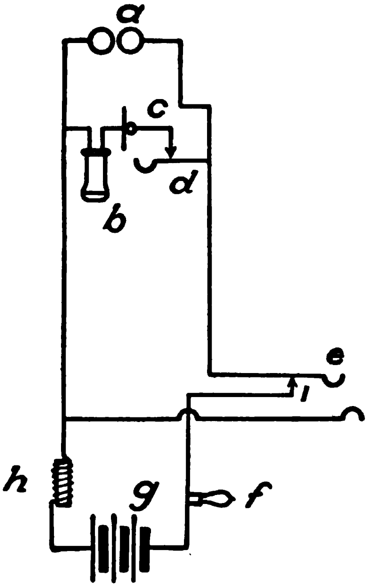


Fig. 234.

AUTOMATIC SIGNALS.

In addition to gaining the advantages already mentioned in connection with the maintenance of the apparatus, the current from the common battery is made use of to operate automatic signals so that the service may be expedited by their greater reliability and quickness of action. The scheme adopted for working this automatic signal, is to provide a lamp so wired to each subscriber line, that when the receiver is lifted from the hook at the subscriber station, it will be lighted.

The plan first adopted was to equip each subscriber telephone with a bell, the resistance of whose coils was 6,000 ohms instead of the usual 1,000. The wiring was as shown in Fig. 234 in which *a* represents the bell coils having a resistance of 6,000 ohms, *b* the receiver, *c* the transmitter, and *d* the hook switch. One side of the line runs through the retardation coil *h* to the common battery *g*, while the other side passes through the lamp *f* and the contact point 1 of the jack *e*. The battery *g* is continually on the line, and current flows constantly through the bell coils. On account of their high resistance, however, the volume of the current flow is not sufficient to illuminate the lamp.

Upon the receiver being removed from the hook, the bell coils are shunted by the circuit through the hook switch, transmitter, and receiver, and the current flow is thereby sufficiently increased to light the lamp. As far as the operator is concerned, this lamp answers the purpose of the drop, and upon seeing it light, she plugs into the jack to answer. When the plug enters the jack, the contact is broken between the upper jack spring and point 1, cutting off the portion of the circuit containing the lamp and putting it out.

The talking battery is connected to the operator's cord circuits in a manner to be described later. The retardation coil *h* is used for preventing cross-talk. It must be remembered that the battery *g* is common to all lines, and while the resistance of the bell coils of one subscriber telephone is sufficiently high to prevent an appreciable amount of current from flowing, yet when several such bells are bridged to this battery, the resistance of the combined circuit is very much less, and as a result, a large leakage from the battery takes place.

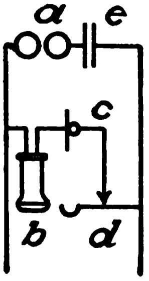


Fig. 235.

For example, suppose that there were 100 subscriber telephones bridged to one battery in an exchange, which figure is very small. If each bell had a resistance of 6,000 ohms, the combined resistance of the whole bridge would be 60 ohms, which would allow of a very serious drain on the cells. To overcome this defect, a condenser was made use of, and the wiring of the telephone was as shown in Fig. 235, in which *a* again represents the bell coils, *b* the receiver, *c* the transmitter, and *d* the hook switch. At *e* is shown a condenser which is cut in series with the bell coils. This condenser presents an open circuit to the direct current from the battery, although it allows the alternating current from the ringing machine to pass through readily.

With this style of wiring, while the receiver is on the hook there is absolutely no current passing through the telephone, so that there is no drain upon the battery.

The telephone wiring shown thus far, included no induction coil. A further step was necessary to provide for this piece of apparatus. When this was done, the instrument was brought to its present condition. The plan of the wiring of the fully-developed common battery telephone is shown in Fig. 236. As in the other form, the bell *a*, wound to the usual resistance of 1,000 ohms, is bridged across the line in series with the condenser *g* whose capacity is 2 M.F. Connected to the No. 1 side of the line is one terminal of the primary winding *e* of the induction coil, while the other terminal of this coil is connected to the contact point. The transmitter *c* is connected to the hook switch and to the No. 2 side of the line. The secondary winding *d* of the induction coil has one terminal connected to the contact point and the other to one terminal of the receiver *b*. The other terminal of the receiver is connected between the bell *a* and the condenser *g*.

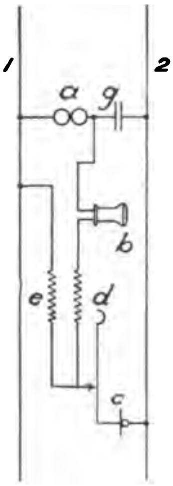


Fig. 236.

The action of this telephone is as follows: The receiver being on the hook switch, the line is open through the condenser to the direct battery current, but the alternating ringing current can readily pass through so that the subscriber can be rung in the usual manner. When the subscriber removes the telephone from the hook switch, a circuit is formed from the No. 1 side of the line through the primary winding of the induction coil to the hook switch, thence through the transmitter to the No. 2 side of the line. When the transmitter is spoken into, a variable current flows over the line from the battery in the exchange, passing through the primary winding *e*. An alternating current is thereby induced in the secondary coil *d*, which flows through the receiver *b*, the condenser *g*, the No. 2 side of the line, to the transmitter, through which it passes back to *d*.

After much experimenting, the wiring of the subscriber's line shown in Fig. 237 has been adopted by the Bell companies as the best suited for general use. The subscriber telephone is shown at the left-hand side, and the line is seen running between it and the main distributing frame *w*. The multiple jacks are seen at *a*, *b*, and *c*, and the answering jack at *d*. So far, the arrangement is very similar to that of the bridging board. The jack used here is of simpler design than that of the bridging board. It is made up on two contact springs 1 and 2 and the ring 3. The contact spring 2, when the plug is in the jack, touches the tip. The spring 1 touches a brass ring on the plug, while its shank makes contact with the ring of the jack. The jacks are bridged across the line in the same manner as in the plain bridging system.

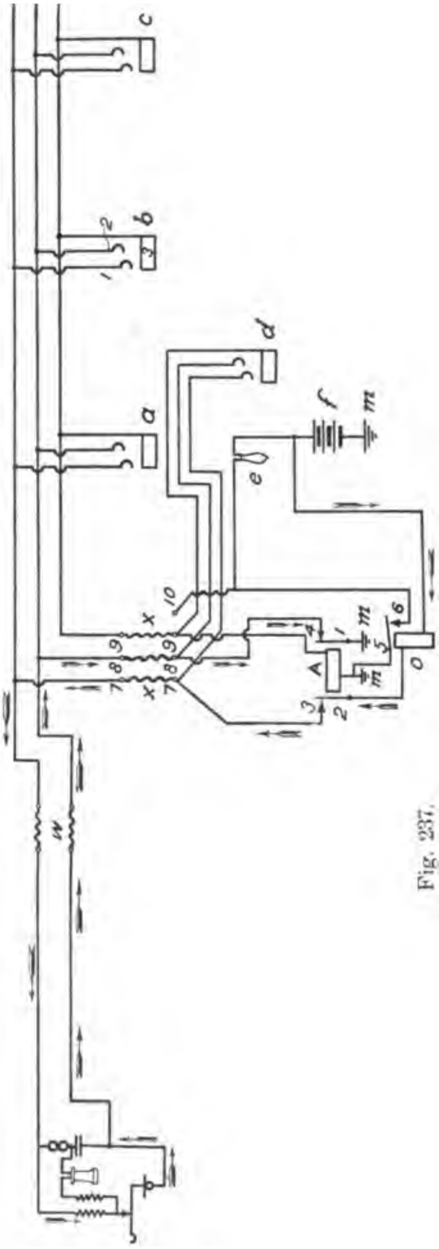


Fig. 237.

The horizontal side of the intermediate distributing board *x x* has three lugs 7, 8, 9, and the vertical side is equipped with four, 7, 8, 9, and 10. The two sides of the talking circuit are connected to lugs 7 and 8 on both sides of the board, while the wiring running from the ring of the jack is soldered to lug No. 9.

On the vertical side of the board is seen a fourth lug 10, to which is connected a wire running from the line lamp *e*. Two relays are seen. The one marked A is known as the *cut-off relay;* it has one terminal of its coil connected to lug No. 9, and therefore to the wire running from the rings of the jacks. The other terminal of this coil is grounded at *m*. Attached to the armature of this relay are two springs 1 and 2, which are insulated both from each other and from the armature. When the relay is not energized, these two springs make contact with the two points 3 and 4, to which are connected the two sides of the talking circuit, No. 4 being connected to that side of the line that touches the tip of the plug. Spring No. 1 is grounded at *m*, while No. 2 is connected to one terminal of the line relay *o*. The other terminal of the coil of the relay is connected to the grounded battery *f*. This relay has one armature 5 grounded at *m*, and one contact point 6, which is connected to lug 10, and therefore to the wire running to the lamp *e*.

The action of this circuit is as follows: When the receiver is on the hook at the subscriber station, the line is open through the condenser. Upon the receiver being removed from the hook and a path formed through the primary coil and transmitter, the current flows from the battery *f* in the direction indicated by the arrows. The line relay will therefore become energized and its armature 5 drawn against the contact point 6. A second circuit is now formed from the battery *f* through the lamp *e* to the lug 10, to the contact point 6, to the armature 5, and to ground at *m*. The lamp becomes lighted. The subscriber operator upon seeing the lamp become illuminated, plugs into the answering jack *d*.

For the present all that will be necessary to know is that on the shank of the plug is a battery and upon touching the ring of the jack, current flows along the wire to lug No. 9, thence through the coil of the cut-off relay A to ground at *m*. This relay being energized, the two springs are pulled away from their respective contacts, and the current is cut off from the line. As a result, the relay *o* ceases to be energized, its armature 5 falls away from the contact 6, opening the circuit through the lamp *e*, and putting it out.

We may sum up the conditions under which this circuit works as follows: The potential of the common battery *f* is on the line constantly. Owing to the presence of the condenser in the bell circuit, however, no current flows. Directly the receiver is removed from the hook switch, current flows through the line relay to the subscriber telephone and back, lighting the line lamp and giving the operator the signal that attention is required. The operator, upon plugging in to answer, energizes the cut-off relay which operates to disconnect the battery from the line, breaks the circuit through the line lamp and puts it out.

The wiring of the operator's cord circuit should be understood next. The plan of the wiring is shown in Fig. 238, and the similarity will at once be seen between this arrangement and that of the outline circuit shown in Fig. 231. A repeating coil having four windings is connected to the common battery as shown. The windings 1 and 2 are connected to the calling plug *a*, those marked 3 and 4 are connected to the plug *b*. The common battery (one side being grounded) is connected to the junction between 1 and 3 and 2 and 4. Wired in series with the side of the cord circuit leading to the ring of the plug are two relays *d* and *d'*. From the point *m* two battery leads run, one to each of the two lamps *e* and *e'*. In series with these two lamps, and between them and the shank of the plug, are two German-silver resistances *f* and *f'*. From the point *o* two leads run to the armatures *h* and *h'* of the relays *d* and *d'*. Two other resistances *g* and *g'* have one terminal

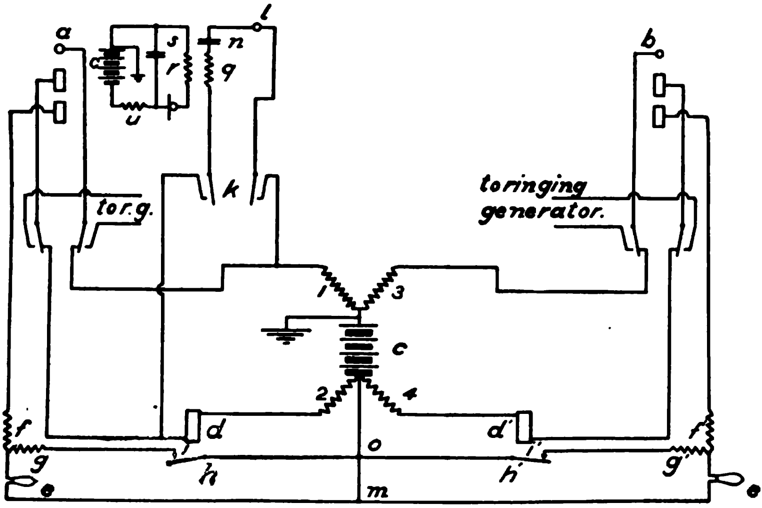
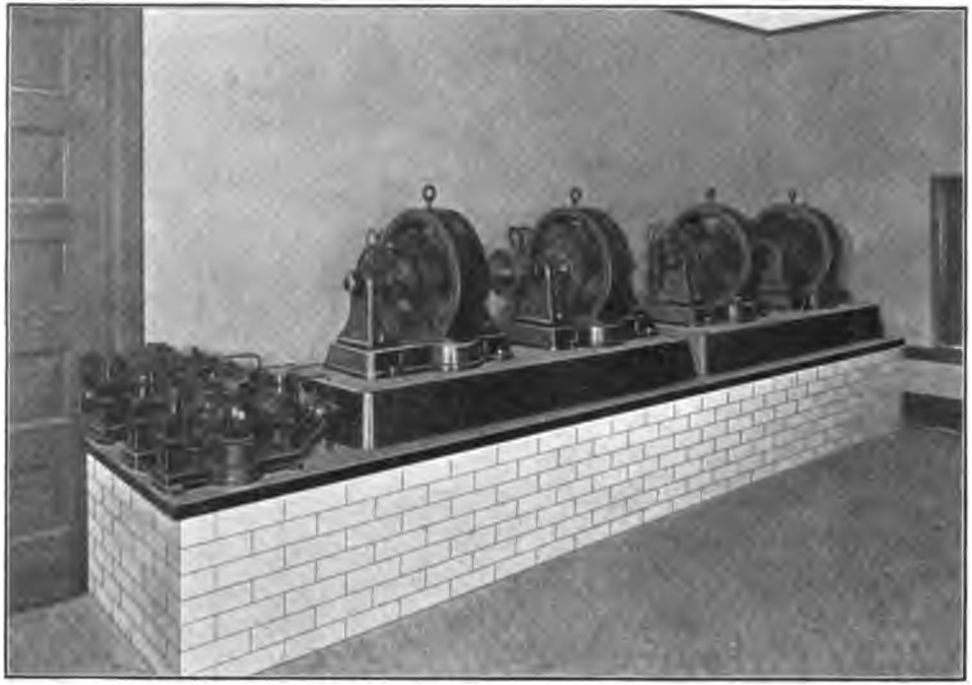


Fig. 238.

connected to the contacts *i* and *i'* respectively, and the other terminals to *f* and *f'*. The listening key is shown at *k*, and acts in the usual way to bridge the operator cord circuit across the cord circuit. It will be observed that a condenser *n* is cut in between the receiver *l* and the secondary winding *q*. This is done to prevent the current from the battery *c* from flowing through the receiver when the operator listens in. The primary circuit contains in addition to the transmitter and receiver, a retardation coil *u* and a condenser *s*. It must be remembered that the battery *c* is common to the exchange, and furnishes all the current used; that on the line circuit, that on the cord circuits, and that on the operator's transmitters.

When the common battery system was introduced it was thought best to provide a separate battery for the line signals, a separate battery for the operator's transmitters, and a separate battery for the cord circuits. The potential used for the first was 6 volts, that for the second was 4, and that for the cord circuits 24. It was soon discovered that everything could be run off the 24-volt circuit, so that this potential was adopted as standard for the common battery system. The proper understanding of this point is essential to the thorough comprehension of the subject.

Returning to the operator's transmitter circuit, the retardation coil *u* is placed in circuit to guard against cross-talk. Its resistance is about 100 ohms, which serves to reduce the current furnished to the transmitter, down to the proper amount. The condenser *s*, having a capacity of 2 M.F., being bridged across the transmitter and primary coil, assists the retardation coil in keeping out cross-talk; for if any of the talking current from some other operator's set, should leak past the retardation coil, it will be absorbed by the condenser rather than pass through the transmitter and primary coil, which is possessed of high self-induction.



RINGING MACHINE FOR KELLOGG HARMONIC FOUR-PARTY SYSTEM.

TELEPHONY.

PART V.

AUTOMATIC SIGNALS.—(Continued.)

Returning to the cord circuit—it will be seen that current is furnished to both the answering and calling plugs through the retardation coil. Following the wiring of the shank of the plug, it will be seen that, when the plug is inserted into the jack, current is sent from the battery through the lamp and resistance to the shank, thence through the shank wire to lug 9, Fig. 237. From this point it passes through the coil of the cut-off relay A to ground at *m* energizing the relay and cutting off the direct battery from the line. The resistance of the lamp, the coil in series, and the cut-off relay are so proportioned that sufficient current is allowed to flow to energize the relay and to light the lamp. When the relays *d* and *d′*, Fig. 238, are energized, their armatures are drawn up against the contact points, and shunt circuits, through *g* and *g′*, are placed on each lamp. These shunt resistances are so proportioned that the current flowing through the lamp is reduced sufficiently to prevent illumination. Using the 24-volt battery, the cut-off relay A is wound to a resistance of 30 ohms, and the series resistances *f* and *f′* each have a resistance of 83½ ohms. The lamps *e* and *e′* are designed to operate on a potential of 12 volts, so that a resistance equal to their own must be placed in series, thus the combined resistance of the cut-off relay and coil *f* or *f′* is 113½ ohms, which equals the resistance of the lamp.

The resistance of the shunt coils *g* or *g′* must be of the proper magnitude to reduce the current flow through the lamp to prevent it from being illuminated. When the shunt circuit is open the total resistance of the circuit on the shank is $113\frac{1}{2} + 113\frac{1}{2} = 227$. The E.M.F. being 24, the current flow $= \frac{24}{227} = .105$ amperes, which amount is sufficient to illuminate the lamp. This lamp will just glow very faintly with .06 ampere.

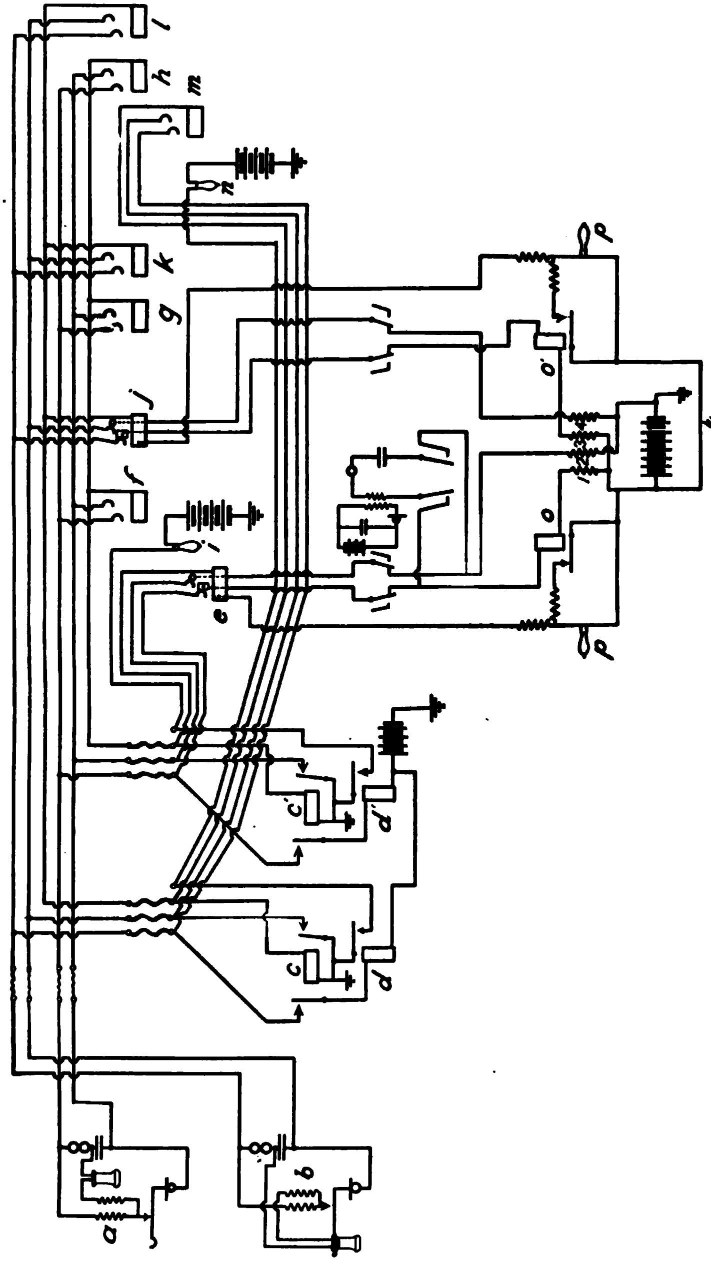


Fig. 239.

It has been found by experiment rather than the result of calculation that a shunt resistance of 40 ohms will sufficiently reduce the brilliancy of the lamp to produce the desired effect. Suppose the resistance of the shunt coil to be 40 ohms, and suppose its circuit to be closed. The total resistance of the shank circuit will then become

$$30 + 83\tfrac{1}{2} + \frac{1}{\frac{1}{113\frac{1}{2}} + \frac{1}{40}} = 143 \text{ ohms.}$$

The total flow of current in this circuit will be given by the expression $\frac{24}{143} = .17$ ampere.

The current will divide itself between the lamp and shunt resistance in inverse ratio to the two resistances, or as 40 : 113, which proportion gives a current flow of .06 amperes, which is sufficient for the purpose.

The relays *d* and *d'* deserve special mention. Since they are both placed in the talking circuit, some device must be used for rendering them as feeble a barrier to transmission as possible. They must also be proof against cross-talk. The first point is accomplished by providing each relay with two windings—one having a resistance of 10 ohms and being wound inductively, the other having a resistance of 100 ohms and being wound non-inductively. The direct current from the battery selects the low resistance inductive path of 10 ohms, because this current sets up little or no counter E.M.F. of self-induction. The talking current which is alternating, and therefore capable of setting up a counter E.M.F., chooses the high resistance non-inductive path.

HANDLING A CONNECTION.

Before giving a more thorough explanation of the manner in which transmission is carried on over this circuit, it will be necessary to explain the method of handling a connection. This will be done by reference to Fig. 239. Suppose *a* and *b* to be two subscribers' telephones. The multiple jacks connected to *a*'s line being shown at *f*, *g*, and *h*, and the answering jack and line lamp at *e* and *i* respectively. The multiple jacks on *b*'s line are shown at *j*, *k*, and *l*, and the answering jack and line lamp at *m* and *n* respectively. Suppose that *a*, desiring to call, raises the receiver from the hook, thereby lighting the line lamp *i* in the manner already shown. The operator, sitting before the answering jack, plugs into the answering plug with the result that current is sent through the shank wire of the plug to the ring of the jack, and thence through the cut-off relay *c'* to ground, thereby cutting off direct battery and putting out the line lamp. The receiver being off the hook at *a*, current flows out on the line through the windings 1 and 2 of the repeating coil. Therefore, the supervisory relay *o* is energized and the shunt circuit being closed, the lamp *p* does not glow. At this stage, the subscriber's transmitter is fed by current sent out through the repeating coil, direct battery is cut off the line, the line lamp circuit is opened, and the supervisory lamp shunted out.

Suppose that the call is for subscriber *b*. The calling plug is pushed into the multiple jack *j* of *b*'s line and the ringing key depressed. The condition shown in the illustration is that existing before *b* has removed the receiver from the hook switch to answer. The calling plug being in the jack *j*, the cut-off relay *c* is energized, and the direct battery cut off the line. The receiver at *b* being on the hook, the line is open at the condenser, so that no current flows through the supervisory relay *o'*. Therefore, the shunt around the lamp *p'* is opened and the lamp illuminated. Directly *b* removes the receiver from the hook to answer, the line is closed through the primary coil and transmitter, current flows from the battery, through the windings 3 and 4 of the repeating coil to the telephone, the relay *o'* is energized, with the result that the shunt around *p'* is closed, and *p'* dimmed And this is the state of things during conversation.

At the completion of the conversation, both telephones are hung up, and both lines again opened. Current therefore ceases to flow through *o* and *o'*, and as a result, the shunt circuits around *p* and *p'* are opened, and both lamps become illuminated. Upon seeing this the operator instantly clears the connection.

It will be observed that these supervisory signals are much more efficient than the ring-off drop since they are independent and automatic. The clearing-out drop necessitates the additional work on the part of the subscriber of the ringing, upon the completion of the conversation, a thing which took time and was often forgotten, and when forgotten the operator either left the connection up or was put to the necessity of listening in to find out whether or not conversation was going on. With the signal system just shown the case is different. The proper operation of the signals depends only upon the act of hanging up the receiver, a thing not so likely to be forgotten as the additional work of ringing off. While subscribers do sometimes forget to hang up, it is not probable that both will forget to do so, and since the supervisory signals work independently, the action of one subscriber hanging up, lights the signal on his side of the cord circuit. The operator seeing this would clear the connection.

The connection being cleared, the cut-off relays are released, direct battery is thrown in on the line, and the original condition is again established. In Fig. 239 the ringing current generator is not shown wired to the key for the sake of clearness.

It will now be time to say a word more on the subject of the method of transmission. Suppose the subscriber at *a* to be transmitting to the party at *b*. In speaking into the transmitter, a variable current is made to flow from the common battery through the windings 1 and 2 of the repeating coil, over the line to and through the primary coil and transmitter at the telephone. This variable current does two things. At the telephone end, it sets up a talking current in the secondary winding of the induction coil, which flows through the receiver, condenser, transmitter and back to the coil again. This is side tone. At the repeating coil, this variable current sets up a talking current in windings 3 and 4 which flows over the other line—the receiver supposed to be off the hook—and passing through the primary winding, receiver secondary winding and condenser, reproduces the sound. The windings 1 and 2 act as the primary of an induction coil, while 3 and 4 act as the secondary. When *b* transmits to *a*, the action is the same but in the reverse order. The windings 3 and 4 then become the primary, and 1 and 2 the secondary.

While the common battery system is excellent for rapid service, and while it tends towards a better and cheaper maintenance, the transmission is not so good as that of the local battery system under the best conditions.

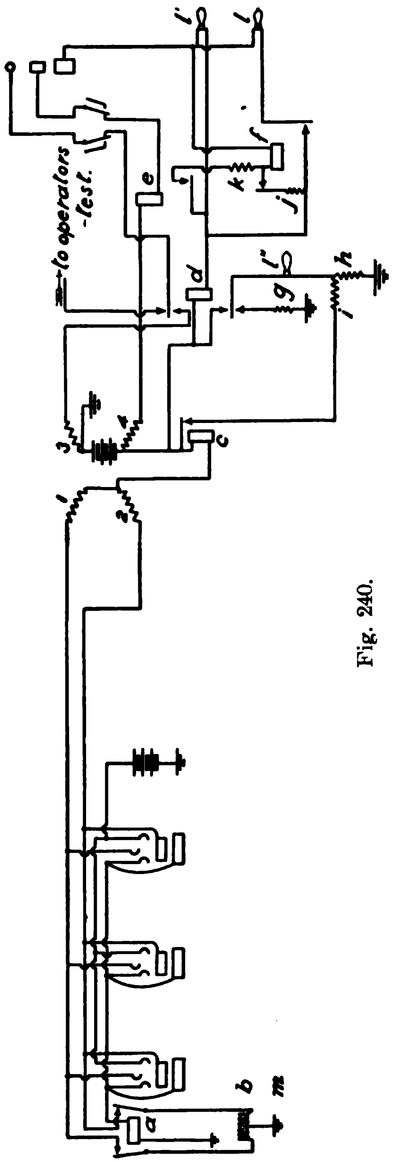


Fig. 240.

The line and cut-off relays are mounted upon a separate rack, and the line lamp only is on the face of the board in addition to the jack. The line lamps are mounted in the same strip with the answering jack, each lamp being directly below the jack to which it is attached. The sections, as is the case with all multiple boards, both series and bridging, are made to accommodate three operator positions each. The supervisory relays and the 83½- and 40-ohm resistance coils are mounted in the rear of the switchboard. The supervisory lamps *p* and *p'* etc., are mounted in the keyboard in two rows directly in front of the cords.

Trunking. With the introduction of the common battery system came additional changes in the trunking systems, which reduced the time of making and clearing a connection to a minimum. In Fig. 240 is shown the wiring of a trunk from a magneto switchboard to one operating under the common battery system. The magneto switchboard selected is of the bridging type, but the method of operating is the same for the series board. At the outgoing end is a relay *a* wired in series with the busy-test battery. To the two contact springs is wired a retardation coil *b* of high impedance, and having a resistance of 600 ohms. When a plug is inserted into a jack this retardation coil is bridged across the line. Its center point is grounded at *m*. At the incoming end is the repeating coil with the four windings 1, 2, 3, and 4. The first two are strapped together, and the battery is wired between the other two. The wire running to the shank of the trunk plug passes through a relay *d* and a lamp *l'*. The upper spring of this relay is wired to the tip of the plug, while the lower spring is wired to the lamp *l''*, the other terminal of which is connected through a resistance *h* of 100 ohms to ground. Wired to one side of the battery is the relay *c*, called the trunk-line relay, whose resistance is 25 ohms. The other terminal of this relay is wired to the strap on the repeating coil.

The armature of the relay *c* is wired to the battery, while the contact is wired through a 30-ohm coil *i* to the junction of *l''* and *h*. The inner contact for the lower spring of the relay *d* is wired to the battery, while the outer contact is wired through a 25-ohm coil *g* to ground. The relay *e*, which is of the same type as that on the operator's cord circuit shown in Fig. 239, has the armature connected to the shank wire of the plug, and the contact, through a resistance *k* of 30 ohms to the coil of the relay *f*, a strap being extended to the left-hand inner contact. The left-hand spring of the relay *f*, is wired to the battery through the resistance *j* of 60 ohms, and the right-hand inner contact is strapped across. The right-hand spring is connected to one terminal of the lamp *l*, the other terminal of which is wired to the shank of the plug.

It will be seen at a glance that the upper spring of the relay *d* performs the functions of an automatic testing key. The method of handling connections over this trunk is the same as that already described. The trunk operator having received the call in the usual way tests the line called for in the manner already described, and assuming the line not busy, plugs in. A circuit is instantly formed along the wire to the shank of the plug, thence through the cut-off relay on the called subscriber's line to ground. The relay *d* is energized, the trunk closed through at the upper side, and current sent through the lamp *l''* and resistance *h* to ground on the lower side. The trunk operator rings the subscriber. When the subscriber operator plugs into the trunk jack, the relay a is energized and the grounded retardation coil b bridged across the line. Current then flows through the trunk line relay c along both sides of the trunk in parallel to the ground at m, energizing the relay c and closing the armature against the contact. Directly this happens the resistance coil i is connected in shunt across the lamp l'', making its illumination invisible, or "shunting it out", as it is called. When the called subscriber removes the receiver from the hook, current is sent out to him through the relay e energizing it and closing the armature against the contact, with the result that current is sent through the resistance k and the relay f forming a shunt around the lamp l'. The current passing through f energizes it and the two springs are closed against their respective contacts. On the left-hand side current passes through the resistance j, the contact and coil of the relay f, thus causing the coil j to be shunted around k. Sufficient current is drawn from l' to shunt it out. The spring and contact close the circuit through the lamp l; but this lamp is also shunted out by the same circuit. Upon the completion of the conversation and the consequent hanging up of the receiver by the called party, the relay e is released, its armature falls away from the

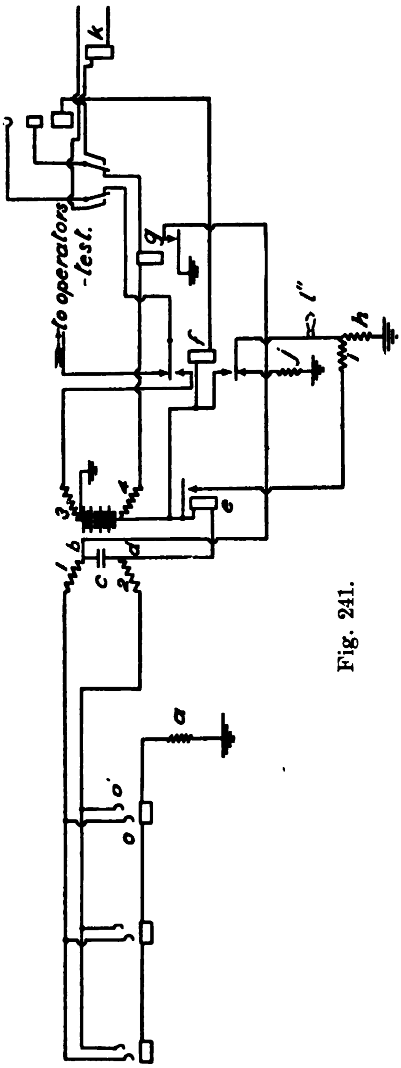


Fig. 241.

contact and the circuit through *k* is opened. The relay *f*, however, does not release because it is locked through its left-hand spring and contact, and the lamp *l'* still remains shunted out. The lamp *l*, however, being of a lower resistance than *l'*, lights up the instant that the circuit through *k* is opened, and therefore serves as a signal to the trunk operator that the called party has hung up.

Upon the subscriber operator clearing the connection, the ground is taken off the outgoing end of the trunk, the trunk line relay *c* is therefore released, and the shunt through the coil *i* removed from the lamp *l''*, which instantly lights up. The trunk operator clears the connection either upon seeing the lamp *l* or the lamp *l''* light up, according to instructions. As a usual thing the lamp *l''* is taken as the signal, which means that the trunk operator waits for the subscriber operator to clear out, before doing so herself. The lamp *l''* also serves as a guard lamp against cut-offs.

Should the trunk operator through carelessness or other cause clear the trunk during the process of conversation, the lamp *l''* will instantly light up, because the connection being up at the outgoing office the ground *m* is still on the trunk, and the trunk line relay energized. The trunk plug being removed from the subscriber jack, the relay *d* is released, and the lower spring leaves the inner contact and touches the outer one. A circuit is therefore formed through the resistance *i*, the lamp *l''* and the resistance *g* to ground. The coil *h* becomes a shunt on the lamp but its resistance is too high to shunt the lamp out.

In Fig. 241 is shown a trunk between two common battery offices. It will be seen to be much simpler than the one previously shown. A condenser *c* is cut in between the windings 1 and 2 of the repeating coil. From the point 1 a wire extends to the contact on the supervisory relay *g*, the spring of which is grounded. The trunk line relay *e* is wired to the point *d*. With the exception of the ringing key, the rest of the wiring is the same as that already shown. The wiring of the ringing key is for what is known as *machine ringing*. The ringing key is provided with a catch, which, when the key is depressed, holds the contacts in the position to allow the ringing current to flow over the line. Wired in series with the ringing machine is a magnetic clutch *k* which is so adjusted that, when the called subscriber removes the receiver from the hook to answer, it is energized sufficiently to trip the catch and cut off the ringing current. This arrangement saves a good deal of the trunk operator's time, and prevents ringing in the called subscriber's ear.

The best feature of this circuit lies in the fact that by means of it the subscriber operator has her supervisory signal controlled by the called subscriber's hook switch. Referring to the outgoing end of the trunk, the ring of the jack is wired to ground through

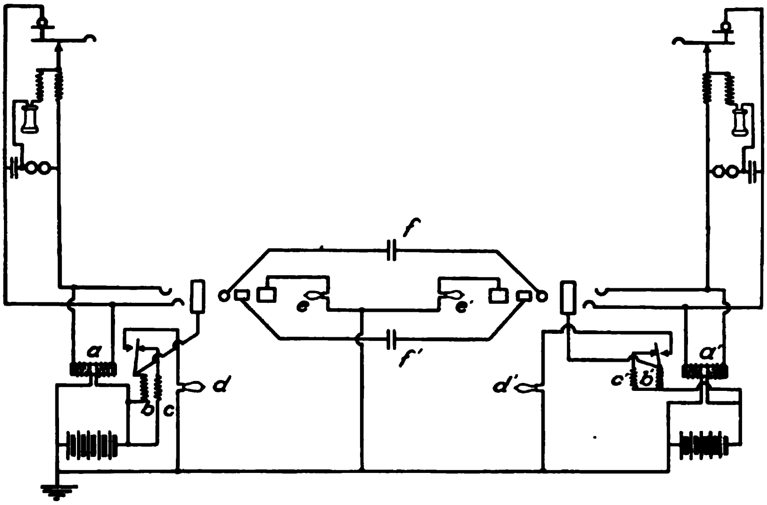


Fig. 242.

a coil *a* having a resistance of 36 ohms, so that the shank circuit of the operator's cord circuit will be completed. A plug being inserted into the trunk jack, the supervisory lamp lights. The ring of the plug sends current out through the jack spring *o* over one side of the trunk to the point *b*, and thence to the contact point of the supervisory relay *g*. The tip of the plug, touching the jack spring *o'* puts a ground on it because it is connected to the grounded side of the battery, and therefore a current flows through the trunk line relay *e* to the point *d* and thence over the opposite side of the trunk to ground through the tip of the plug. The relay *f* and the lamp *l''* work exactly the same as shown in Fig. 240. The called party taking the receiver from the hook energizes the relay *g*, closing the spring against the contact. Current now flows through the supervisory relay on the subscriber operator's cord circuit to the jack spring *o* to the ground, energizing the relay and shunting out the lamp. When the called subscriber hangs up upon the completion of the conversation, the relay *g* is released, the ground taken off the contact, and therefore the circuit over which flowed the current through the subscriber operator's supervisory relay is broken. The shunt on the supervisory lamp being thus removed, the lamp lights, just as if the called subscriber's line had terminated in the same exchange as the calling line. This form of trunk circuit is the most efficient ever devised.

There are three weak points about the common battery line and operator's cord circuits that have been shown so far, and they are:

First, when the operator plugs in to answer a call the subscriber hears a painful click in the ear, caused by the direct battery being suddenly cut off the line through the cut-off relay. Second, during conversation current is required to keep the cut-off relay energized. Third, the presence of a relay in the talking circuit.

In Fig. 242 is shown a very simple circuit which does away with the click in the ear upon the operator answering. In this circuit the battery is permanently connected to the subscriber lines through the relays *a* and *a'*. The armature of the relay rests normally against the outer contact point, the inner contact being connected to the lamp *d*, whose other terminal is connected to the grounded side of the battery. The armature itself is connected to through the resistance *b* to the free side of the battery. The tip and ring of the plug form the connections of the talking circuit, the two shanks being connected together through the lamps *e* and *e'*, one side of each being grounded. Two condensers *f* and *f'* are cut into the talking circuit.

Referring to the left-hand line, when the subscriber removes the receiver from the hook switch current flows through the relay *a*. The armature is pulled against the inner contact, and current flows through the resistance *b* and the lamp *d* to ground. The lamp becomes illuminated. The operator plugging in to answer, throws a ground on the ring of the jack through the shank of the plug, which shunts the lamp *e* across the lamp *d*. The resistances and current-carrying capacities of these two lamps are so proportioned that both are shunted out.

When the subscriber hangs up, the relay *a* ceases to be energized, the armature falls against the outer contact opening the circuit through the lamp *d*. The two coils *c* and *b* are connected together through the lamp *e* with the result that the latter lights as the shunt has been removed.

Since the battery is permanently connected to the line, the click in the ear is done away with, as is the presence of the relay in the talking circuit. The current passing through the two lamps in multiple is fully equal to that taken by the cut-off relay, so that no saving is accomplished in this manner. This circuit provides no busy test as current is continually on the ring of the jack. It is consequently not suited for multiple switchboards

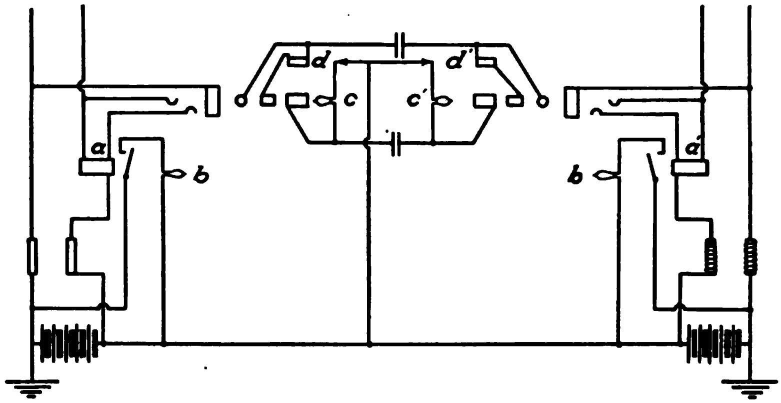


Fig. 243.

Another form of circuit is shown in Fig. 243 which aims at reducing the amount of current used up in shunting out signals during conversation. As in the previous one, the battery is permanently connected to the line through a retardation coil. When the subscriber removes the receiver from the hook the relay *a* becomes energized closing the lamp circuit *b*. Referring to the cord circuit, the talking contacts here are the tip and the shank and upon the plug being inserted into the jack, current flows along the wire from the ring through the supervisory relay *d* to the tip of the plug and thence out on the line. The relay is energized, and the armature pulled away from the contact. The current through the relay *a* is so far shunted as to cause it to release, and open the line lamp circuit. When the subscriber hangs up, the relay *d* is released, the armature falls against the contact and lights the supervisory lamp. This circuit has some good features, but it is very problematical whether or not it is more economical of current than the one originally shown. In Fig. 244 is shown the general appearance of an exchange switchboard. The one shown is of the common battery type with a capacity of 5,400 lines. The girl seen standing up is called a *supervisor*, and her duty is to see to it that the operators attend properly to their work and also to assist them out of any difficulty that they might get into from time to time. The *chief operator* sits at a desk and has direct charge of all the operators. The whole force is presided over by a manager.

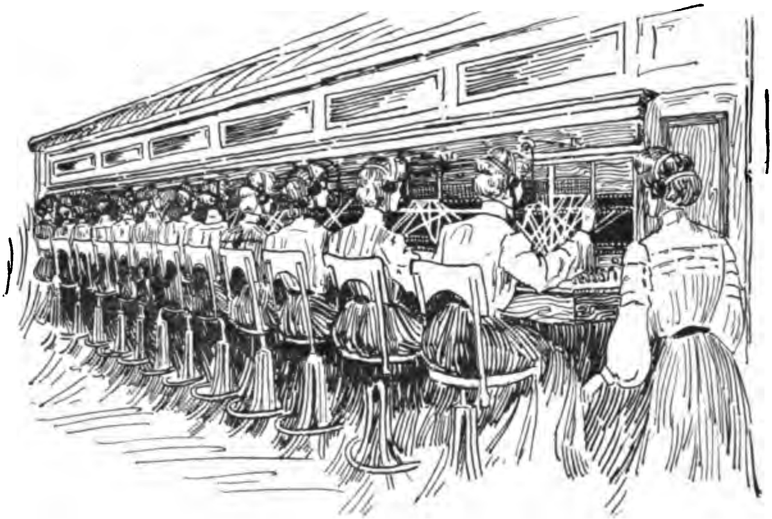


Fig. 244.

TOLL BOARDS.

Long toll lines, upon which a mileage rate is charged, are handled over a special board placed in the most convenient exchange. In cities having only one exchange, and in which the toll business is large, each exchange has a toll board. Toll boards are equipped, in addition to the toll line multiple and answering jacks, with a multiple of the outgoing trunks to other exchanges. For example, the toll board in the Courtland St. exchange, for handling calls to points in Jersey City and Long Island, is equipped in addition to the toll trunks, with outgoing trunks to every other exchange in the city, and also with outgoing trunks to the local switchboard in the Courtland St. exchange. The calls for toll points are handled over what is known as a recording circuit. This is simply a sending order circuit from all the local exchanges to a special operator set aside to receive calls. The calls are written upon tickets, and passed to the toll operators for completion. The toll operator times and supervises every connection. The method of procedure is as follows. Suppose that No. 76, 38th St. calls for No. 56 Paterson, N. J. The subscriber operator at 38th St. answering the call would go in on the recording circuit, to the recording operator at the New Jersey toll board at Courtland St. and say: No. 760, 38th St. wants No. 56 Paterson. The recording operator would note the facts on a slip and pass it to the toll operator handling the Paterson toll trunks. This operator would go in on the order circuit to the incoming trunk operator at 38th St. and order up No. 760. She would then go in on a Paterson trunk and having gotten the Paterson operator ask her for No. 56. This line having been plugged up the connection would be established. The conversation having been completed, the toll operator would disconnect the circuit trunk to 38th St. thus giving the trunk operator there the signal to clear out, and she would ring on the Paterson trunk, and when the Paterson operator answered, she would direct her to clear the connection. Long Distance connection being in substance, toll connections are handled in this manner.

Toll boards are used for two purposes. First, to establish connection between two toll trunks. Second, to establish connection between a toll trunk and a subscriber's line. This type of switchboard, therefore, is equipped with two classes of trunks, viz., toll trunks and trunks to local exchanges. The operator cord circuits must be, therefore, of two classes. That suited for connecting two toll trunks, and that suited for connecting a toll trunk and a trunk to a local exchange. With the magneto system, since both the toll trunks and those to the local exchanges are wired substantially in the same manner, one set of cord circuits will do for both purposes. But with the introduction of the common battery system, where the wiring of the trunks to the local exchanges takes a new form, a corresponding change must be made in the wiring of a portion of the cord circuits. Toll boards are designed on the multiple type, but differ in construction from the local switchboards in the fact that the sections are built to accommodate only two operator positions instead of three. The reason for this change lies in the fact that greater ease is given to the operator thereby, to reach all the jacks in the multiple. With large multiples in use in the local switchboards this device cannot be resorted to on account of the extra expense. For example, suppose that a switchboard is equipped with 5,000 subscriber multiple jacks, and that the calling rate is such that only 50 answering jacks are assigned to each operator. The number of sections needed would be $\frac{5,000}{50 \times 3}$ which is approximately 34. The number of multiple jacks would be, therefore, $5,000 \times 34 = 170,000$. If now these sections were designed for two operators' positions instead of three each, the total number of sections needed would be $\frac{5,000}{50 \times 2} = 50$ and the total number of subscriber multiple jacks would become $5,000 \times 50 = 250,000$ or an increase of 80,000 jacks. Assuming the cost of a jack to be $0.25 the increase in cost due to this change would be $80,000 \times .25 =$ $20,000.00, which would be much in excess of the money saved from better operating.

With the toll board the case is different. Here the multiple, counting the toll trunks and those to local exchanges seldom reaches 700 jacks, so that the extra cost of the jacks is not of so much importance. Again, since in the case of connections over toll trunks a rate is charged which is in proportion to the length of the trunk used, and the length of time during which the conversation is carried on, the return to the company in money is higher per call, than in the case when the connection is handled exclusively over a local board. A toll connection requires more time to establish, for reasons that will be seen directly, than a local connection. The above two facts make it necessary to give the toll operators every advantage.

The trunks to local exchanges are of the same type as those in the local board, and are wired in the same general way. The toll board is situated in the same room, or at any rate, in the same building with one of the local switchboards. For example, the toll board for handling the toll lines to the suburbs of Philadelphia and surrounding towns, is situated in the same building as the local exchange known as No. 2. The toll board for handling the toll trunks to the northern suburbs of New York, throughout the district known as the Bronx, and the outlying towns, is situated in the same building as the local switchboard known as Melrose. The outgoing trunk multiple of the toll board is made up of an extension of the outgoing trunk multiple of the local board, and in addition, a set of trunks to one of the incoming trunk positions of the local board in the building in which it is situated. Thus, at Melrose, the outgoing trunk multiple in the local board is extended through the toll board, and in addition there is a set of trunks to the local board at Melrose. The toll board is thus equipped with trunks to each one of the local exchanges. These trunks are either circuit or ring-down as the case may be.

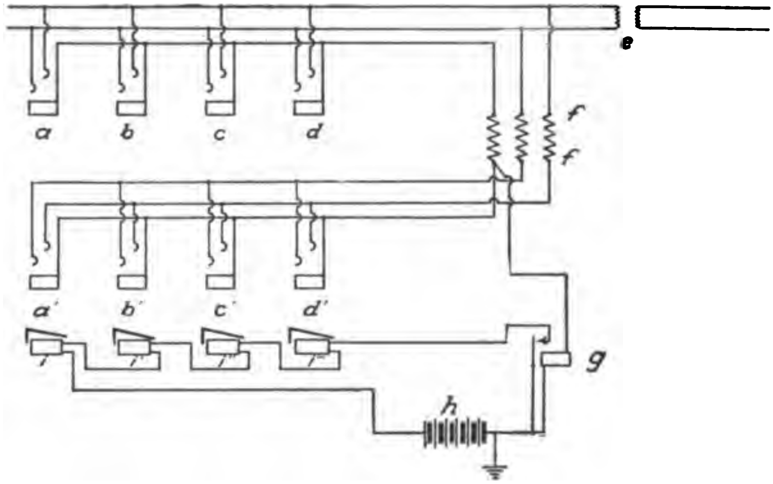


Fig. 245.

In Fig. 245 is shown the wiring of a ring-down trunk, the jacks in the local board being shown at *a* *b* *c* and *d*, and those in the toll board at *a'* *b'* *c'* and *d'*. The lugs on the intermediate distributing board are shown at *f* and *f'*, and the repeating coil at *e*. In the toll board each multiple jack is accompanied with an automatic signal called a *busy visual.* This signal is of the magnetic type, to the armature of which is attached a light aluminum shutter which, when the coil is energized, is pulled over the face of the magnet so as to be in plain view of the operator. When a plug is inserted in a jack, either on the local or toll board, the relay *g* is energized, and its armature drawn against the contact point. Current then flows from the battery *h*, through the coils of the busy visuals in series, energizing them and making the shutters show busy. By this means the toll operators are relieved of the necessity of testing the trunks to find one that is not in use, which tends to save time.

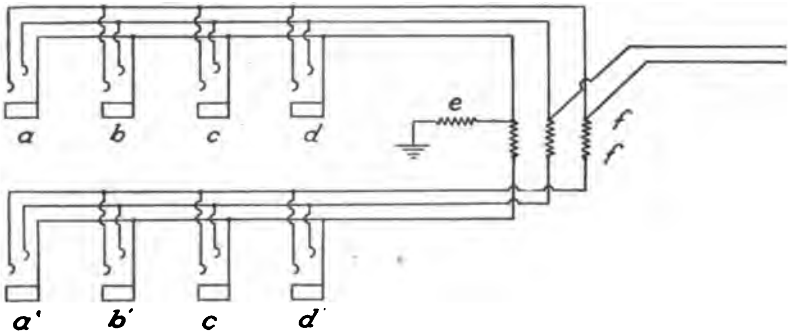


Fig. 246.

In Fig. 246 is shown the wiring of a circuit trunk, the jacks in the local board being shown as before at *a b c* and *d*, and those in the toll board at *a' b' c'* and *d'*. The 36 ohm coil is shown at *e*. In this case, the multiple through the toll board consists merely of a duplicate of that through the local board. The wiring of a toll trunk is similar to that of a ring-down trunk shown in Fig. 245, with the exception that it does not appear in the local switchboard, and that there is an answering jack wired to it and placed on the toll board. It is shown in Fig. 247. The repeating coil is removed and a drop *g* is wired across the trunk. The multiple jacks are shown at *a b c* and *d* and the answering jack and lamp at *e* and *f* respectively. A relay *h*, having two windings *i* and *i'*, is so wired that one of the windings is connected to the restoring coil of the drop, while the other winding is connected to the armature. The opposite terminal of the lamp is wired to the contact point of the drop to which is also connected one terminal of the resistance coil *o*. The opposite side of the busy visuals is wired to the contact point of the relay, and the armature is grounded. The action is as follows: The trunk being rung on from the distant end, and the armature falling, current flows through the lamp *f* and the resistance *o*, through the winding *i′* of the relay *h*, energizing it and closing the circuit through the busy visuals. The trunk is thus shown busy the instant it is rung upon, preventing any operator taking it up before the proper operator answers at the answering jack.

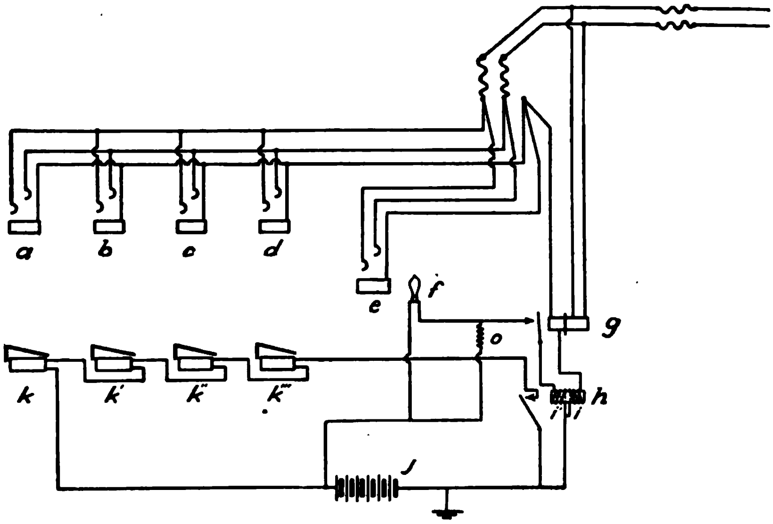


Fig. 247.

When the plug is pushed into the jack, current is sent through the restoring coil of the drop, and the coil *i* of the relay. Therefore, although the circuit through the coil *i′* is broken, that through the coil *i* keeps it energized so that the busy visual circuit remains closed. The resistance *o*, which is 600 ohms, is shunted around the lamp so that, should the latter become open, the busy visuals will be energized when the trunk is rung upon.

In Fig. 248 is shown the wiring of a cord circuit to connect together two toll trunks. It differs in no very essential feature from that of an ordinary bridging board. The clearing out drop *f* is not placed on the board in view of the operator, but a lamp *g* actuated by its armature is placed in the keyboard and acts as the supervisory signal. The resistance *h*, which is in series with the lamp, is 120 ohms, while that of *j*, in series with the restoring coil, is 190 ohms. The resistances of *i* and *k* are 200 ohms each. The wiring of the operator's transmitter circuits is identical with that already shown for a common battery office.

In Fig. 249 is shown the circuit for connecting together a toll trunk and one to a local office. One half is the same as that shown in Fig. 248, while the other half is that of local subscriber's operator's cord circuit. Here the left-hand plug *a* is for the toll-trunk jack, while the right-hand plug *b* is for the trunk to the local switchboard. In this cord circuit a repeating coil is used, and the windings 1 and 2 are strapped together on the left-hand side of the cord, while the battery is connected between 3 and 4 for the right-hand side in the usual manner. A toll board position is usually equipped with 12 cord circuits, and of these 4 are of the type shown in Fig. 248, and the remainder, of that shown in Fig. 249.

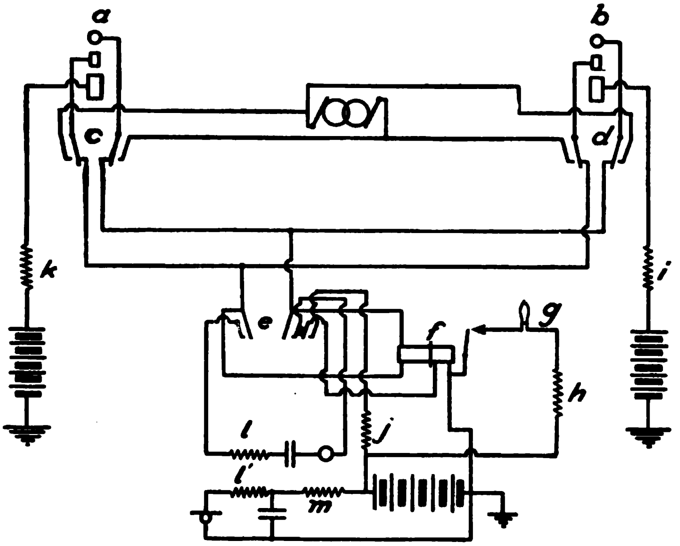


Fig. 248.

LONG-DISTANCE SWITCHBOARDS.

The business done by the Long Distance Company is essentially a toll business, and the switchboards used are, therefore, of the toll board type. They differ, however, in many respects from the toll boards used by the local companies. The types of switchboard used in a Long Distance exchange consist of: *Toll boards*, *Through boards*, and *Recording boards*. The toll boards are those at which the toll lines terminate, and are equipped in the larger offices with the toll line answering jacks, line drops, outgoing trunk multiple to the local exchanges, and circuits to the chief operator's board. The through boards are used to complete connections from one point to another, when the line to these two points passes through the office. For example, if a connection is wanted between Boston and Philadelphia, there being no direct trunks between these two points, the connection would have to be handled through New York. Boston would call New York, and ask for Philadelphia. New York would then raise Philadelphia, and connect the two

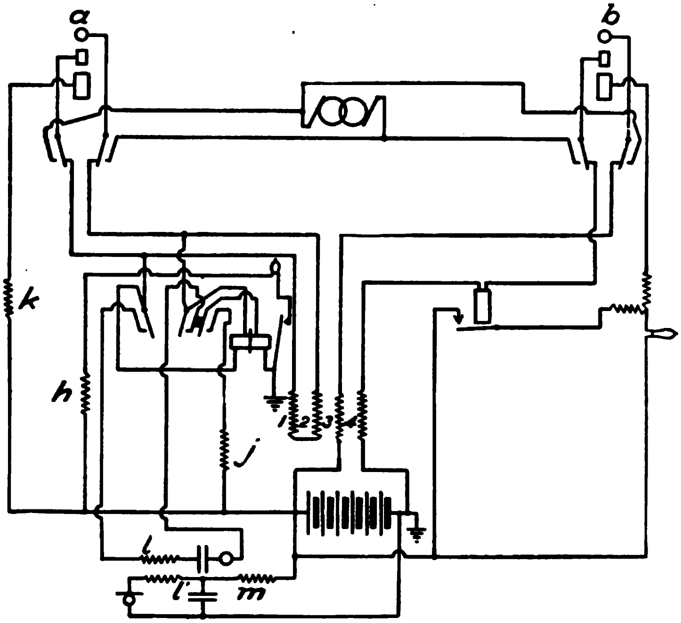


Fig. 249.

trunks together. This would be done at the through board. The recording board is used for handling calls from local subscribers to Long Distance points. The through boards are equipped with a multiple of the toll lines, a multiple of the trunks to local offices, and a multiple of the trunks to the chief operator's board.

The wiring of a toll line is shown in Fig. 250. The main rack is shown at x x', and in this connection it should be said that the main rack of the Long Distance Company is not equipped with protecting devices. The lines after entering the office are equipped with the regular carbon sandwich protector for lightning, as shown at o and o'. The jack a is in the chief operator's board, which contains a bridge on all lines entering the office. The jacks b, c, d represent the multiple in the through boards, while at e is shown the answering jack. After passing the answering jack, the line runs through the contacts of the relay i, which has a resistance of 90 ohms, and thence through the line coil of the drop h. One terminal of the coil of the relay is connected to the ring of the jacks and the other is wired to the restoring coil of the drop. The lamp g is the answering lamp, and those marked f, f', f'', and f''' are the busy lamps. The operation of the circuit is as follows:

The trunk being rung open the drop is thrown and the lamp g lighted. The operator plugging

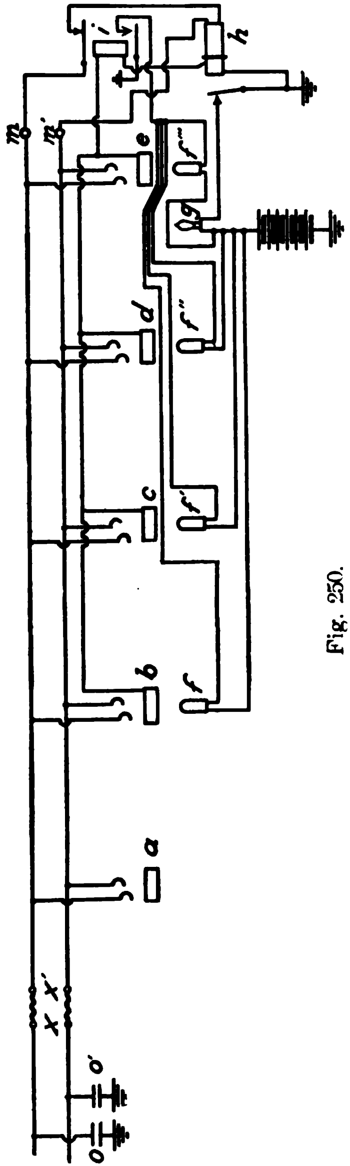


Fig. 250.

into the jack *e* to answer, restores the drop, putting out the light *g*. At the same time the relay *i* is energized and the drop cut off. Also a path is made between the lower spring and inner contact of the relay *i* for the common return of the busy lamps *f*, *f'*, *f''*, and *f'''*, lighting these lamps and giving the signal that the line is in use. It will be observed that the heat coils *m* and *m'* are placed in series with the drop to protect it against sneak currents. The busy lamp *f'''* is placed above the answering jack to notify the operator at that point when the trunk is taken up at any other section of the board.

In Fig. 251 is shown the operator's cord circuit that is used

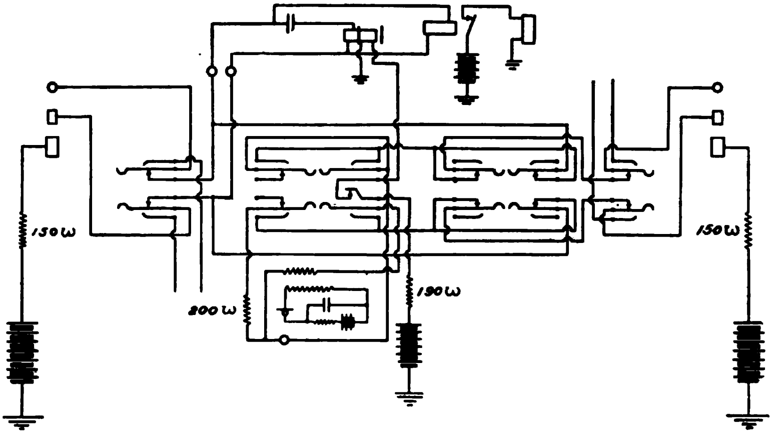


Fig. 251.

on the toll board and through board. The wiring of the trunks to local offices is shown in Fig. 252, and is of a design different from that used between the exchanges of a local company. It is so wired that the long distance operator does all the ringing, and to this end a special relay is placed at the incoming end, which is actuated by the alternating current from the ringing key of the long distance operator. At the long distance office the trunk is wired in the usual manner with the ring of the jacks connected to ground through a coil of 90 ohms resistance. At the incoming end is the regulation repeating coil *a* wired up in the regulation manner, with the exception that the relay above mentioned is bridged around the condenser, with another condenser in series.

The outside contacts of a second relay *b* are also bridged across the terminals of the first condenser, the upper swinging contact of this relay being wired through the coil of a third relay *c* to ground, and the lower swinging contact of this relay being connected to the contact point of the relay *e*. The two inner contacts of the relay *b* are strapped together. The armature of the relay *a* is connected to battery, and its contact point is wired through the coil of the relay *d* and the coil of the relay *b* to ground, through a resistance of 170 ohms. To this wire is also strapped the contact of the relay *e*, its armature being connected to that of the relay *c*. The automatic testing key is wired in the usual manner, with the exception that the lower inner contact is connected to battery, and the lower swinging contact is connected to the contact point of the relay *c*.

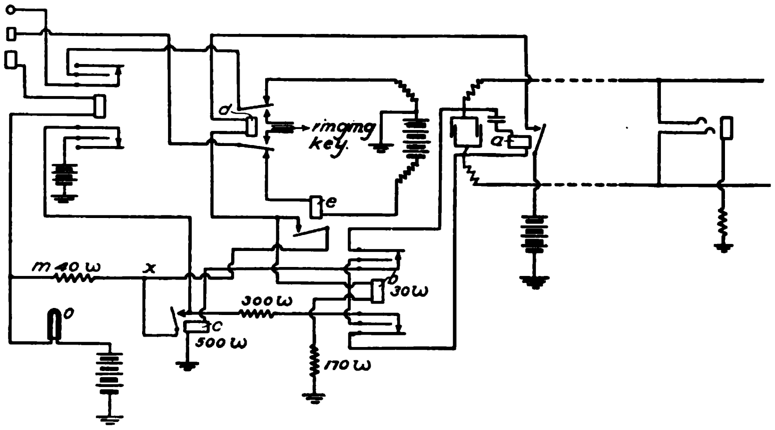


Fig. 252.

The working of this trunk is as follows: The trunk operator at the local office taking up the called subscriber's line, the automatic key is energized, and battery is thrown out on one side of the line to the long distance office, where the keyboard signal is energized. The supervisory lamp *o* is lighted. The Long Distance operator upon ringing, energizes the relay *a*, closing the armature against the contact, and throwing battery through the relay with the result that it in turn becomes energized, cutting in the ringing current and calling the subscriber. This current flows also through the relay *b* energizing it, breaking the contacts between the middle and outer, and making them between the middle and inner points, with the result that current is now sent from the lower contacts on the automatic testing key through the strap on the relay *b* and the coil of relay *c* to ground. The relay *c* becomes energized and its armature is closed against the contact point, thus closing the shunt circuit around the lamp through the resistance coil *m*, shunting out the lamp. When the called subscriber removes the receiver from the hook, the supervisory relay *e* is energized, and current flows through the lamp, and the resistance coil *m*, the armature and contact point of the supervisory relay, and the coil of the relay *b* to ground. The relay *b* again being energized, current is sent through the relay *c* energizing it, and current is again allowed to flow through the lower contacts of the automatic testing key, to the point *x*, where it splits; one portion passing through the coil *m*, again shunting out the lamp. The other portion flows through the armature and contact of the supervisory relay, the coil of the relay *b* to ground, thus keeping *b* and the relay *c* energized. No disconnect signal is placed at the long distance end of the trunk, as the long distance operator is required to supervise the connection.

When the conversation is completed, the operator at the distant office rings on the toll trunk, thus throwing the clearing-out drop. The long distance operator then clears the connection, and the lamp at the incoming end again lights up. The recording boards are used to record calls from local exchanges to long distance points, and to transmit the information to the proper toll operator in order that the required toll point may be reached.

These boards are equipped with a multiple of the outgoing trunks to local offices. The operator's cord circuit is the same as that of a toll board, with the exception that it has only one cord and plug, is used to hold the trunk, until the toll operator takes up the connection. Each recording operator position is equipped with a set of sending order wire keys to the local offices. A special operator, called a *receiving operator*, is equipped with a telephone circuit at which terminates an order circuit from each of the local exchanges. All calls coming from the local exchanges are received over this order circuit by the receiving operator, who writes the details on a ticket and passes it to one of the recording operators. This operator goes in on the order circuit to the trunk operator in the exchange from which the call originated and orders up the calling subscriber's line, which is done in the regular circuit trunk manner. The ticket is then sent from the recording operator to the toll line operator, who proceeds to get the called subscriber at the toll point required. Upon the toll line operator plugging into the trunk to the local exchange upon which the calling subscriber's line is being held, the recording operator withdraws her plug and has nothing more to do with the connection.

TELEPHONE OPERATING.

The work of establishing connections in a telephone exchange is called *operating*. The department that handles the operating is called the *Traffic Department*. The force in a telephone exchange is made up as follows: Each exchange is in charge of a manager, whose business it is to see that the operating force properly attends to the work of handling connections. He should have full authority over his force, being free to make whatever change he may deem to be necessary. In large exchanges his efforts are seconded by one or more assistant managers. These are usually men, although the position of assistant manager is sometimes filled by a woman. The official who comes in the most direct contact with the operators is the chief operator. This position should always be filled by a woman. The force of operators is assisted by one or more supervisors, whose duty it is to watch closely the manner in which the operators directly under her charge attend to business, and to help them out of any difficulties into which they may from time to time fall. Each supervisor is assigned a certain number of sections to patrol, and she walks continually to and fro watching the work. She should watch the manner in which the operators answer the subscribers, insisting that it be done promptly, and that the subscribers be carefully listened to so that their wishes may be properly recorded. The supervisor should see that the subscriber always gets courteous treatment. Each supervisor is equipped with a telephone placed conveniently on the wall so that the operators may be readily able to communicate with her. It is part of her duty to give the operators all the assistance necessary in the performance of their work.

Next to the supervisor in authority comes the monitor. This official sits at a desk so as to be in constant communication with the switchboard. She is required to take up all matters of complaint by the subscribers, to furnish any information that may be required by the subscriber, and to complete connections that the operators have found impossible to complete. The number of monitors required varies with the size of the office, but is seldom over four, and usually two.

Next highest in authority is the chief operator, already referred to, who is somewhat analogous in her relations to the operating force as the first mate of a ship is to the sailors. She sits at a desk somewhat similar to that of the monitor, so as to be in constant touch with the operating force. Her duties are many and various. First of all, she is the person to whom the force report directly. She watches the work, and is the first to note any defects therein. She receives the reports from the supervisors and monitors and acts on them. She is directly responsible to the manager for the manner in which the traffic of the office is carried on. All calls for the manager are given to her, and it is her duty to determine whether to handle them herself or turn them over to the manager for his action.

The night force is presided over by a night manager who has the rank of chief operator. The night force is not so large as that employed in the day, and as a result no night supervisors are needed. Only one night monitor is required and no night chief operator. The manager should see to it, first of all, that he provides himself with the proper kind of a chief operator. This done, one half of the battle for good operating is won. He should then supervise carefully the work of the chief operator, in selecting the proper operators, supervisors, and monitors. He should select such assistants as will best help him in his work.

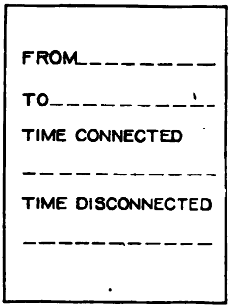
The hours of the operating force are divided as follows: Half of the day force reports at 7 A. M. and the other half at 8 A. M. The half that report at 7 A. M. are relieved at 5 P. M. The second half is split up, the majority reporting at 8 A. M., but a small number reporting at 9 A. M. and remaining till 7 P. M. The hours for reporting usually change every week so that those operators who, during the first week, report at 7 A. M. will, during the second week, report at 8 or 9 A. M. The new operators are formed into a relief squad which reports at 4 P. M. and remains till 9 P. M. As the operators in this squad show increased proficiency they are promoted to the regular force. In some exchanges the night force consists of boys from 16 to 21 years of age. But it has been found after repeated trials that girls give better results than boys, as they are more tractable, so that they are being used more and more every year. The night force reports at 7 P. M., and remains till 7 A. M.

These hours seem very long, and are in actual fact. But a great deal of time during the middle of the night is given to the operators to sleep so that the strain is not as great as would seem at first sight. The telephone companies select these long hours so that the girls will not be compelled to be on the street at any unseasonable hour.

The operators are divided into two groups. Those that answer the subscriber lines, called subscriber or "A" operators, and those that handle the incoming trunks, called the trunk or "B" operators. In offices where there is situated a toll board, there exists a third group called the toll operators. The work performed by each of these groups differs in detail from that performed by the others. The subscriber operators have to deal with the public, and therefore must be well schooled in soothing ruffled tempers and the like. They must also be instructed in the proper method of answering questions. In answering calls a certain formula must be gone through with, which will be described directly. In the early days the operator used to answer the subscriber's call by saying "Hello". But within the past five or six years this custom has been discontinued, and the operators instructed to substitute the word "Number", so that to-day, in all well regulated exchanges the operator answers the subscribers call by saying "Number" with a rising inflection. The operator then gives the number required.

There are two methods of operating, one used with the *magneto system*, and the other with the *common battery system*. That used with the magneto system will be explained first. In explaining the various methods of operating, the multiple board only will be considered, since all methods applicable to this are also applicable to the standard or subdivided board.

There are in all five classes of calls: *First*, those for subscribers in the same exchange as the calling subscriber. *Second*, those for subscribers in other exchanges reached over a ring-down trunk. *Third*, those for subscribers in other exchanges reached over a ring-down trunk through some intermediate exchange. *Fourth*, calls for subscribers in other exchanges reached over circuit trunks. *Fifth*, calls for subscribers reached through the toll board. A system followed now by nearly every telephone company is to give three classes of service. First, *flat rate*, according to which the subscriber is charged a fixed rate per year for unlimited service. Second, *message rate*, according to which the subscriber is charged a fixed rate per year which is regulated by the number of calls made. Third, *pay station*, according to which the subscriber pays for each call made at the time of making the call. It is obvious that a record must be kept of all message-rate and pay-station calls made, while no record need be kept of the flat rate calls. The method of keeping record of the calls is by filling out a ticket such as shown in Fig. 253, on which opposite the word "From" is written the number of the calling subscriber's line; and opposite the word "To" is written the number of the line called for. Pay station calls are limited in time to five minutes, so that two additional blanks on the ticket, one headed "Time Connected", and the other "Time Disconnected", have to be filled out in this case.


FROM________

TO__________

TIME CONNECTED

____

TIME DISCONNECTED

____

Fig. 253.

Consider now the first case in which the called subscriber is in the same exchange as the subscriber calling. The operator having plugged into the answering jack, and said "Number" with a rising inflection as already described, listens intently to the request of the calling party. Assume that 500 calls for 4930. The operator takes up the calling plug and touches the rim of the multiple jack on 4930. If the busy test is obtained, the operator says to 500: "They are busy". If upon touching the jack no busy test is obtained the plug is pushed into the jack and 4930 is rung up. The listening key can be adjusted all this while so as to cut in the operator's telephone, but the operator must be very careful not to have more than one listening key so adjusted at the same time, else the two cord circuits will be connected through her telephone and cross-talk will result. When the called party has answered the operator says: "Are you 4930?", and upon receiving the affirmative answer says: "Go ahead," and the two parties begin conversation. The operator should supervise the connection from time to time in order to see that the subscribers are able to converse properly, and also to determine whether or not they have finished. This latter point is made necessary by the possibility of the subscribers forgetting to ring off. This supervising consists merely of temporarily throwing the listening key on each cord circuit upon which there is a connection. If the operator in so supervising should happen to listen in on a connection over which there is no conversation she should ask: "Are you waiting?" and after a pause: "Are you through?" If no response is obtained she should then take down the connection.

It often happens that the operator has to answer several calls at once In doing so she should answer each calling subscriber in turn, before making any attempt to raise any of the subscribers called for. When the last subscriber has been answered, she should then start in and raise the subscribers called for in the order in which she has received the calls When the party called for does not answer the telephone, the call is reported as a "Don't Answer", and given to the monitor for further trial. If the called subscriber's line is out of order so that he cannot be raised, the fact is so reported to the calling subscriber. All cases of "Don't Answer" or "Out of Order" are reported as lost calls, and the ticket marked with a cross. One of the greatest problems in operating is to reduce the percentage of lost calls. Should the operator, through confusion or any other cause, plug into the wrong jack and call the wrong party, she should allow the plug to remain in the jack until the called subscriber answers, and then say: "Excuse that, please", after which she is free to withdraw the plug and call on the proper line.

The next case to be considered is that in which the called-for subscriber is in another exchange reached over a ring-down trunk. The subscriber operator, having answered the call, tests with the tip of the calling plug of a different pair of cords, usually the one adjacent to that used for answering, the rings of all the jacks on the trunks to the required exchange, until one is found that is not occupied. The calling plug is inserted into this jack and the trunk rung on. When the operator at the distant exchange answers, the first operator asks for the required number, and if the line is not in use the connection is plugged up and the called subscriber rung up by the operator at the distant exchange. When the called subscriber answers, the operator at the originating office asks: "What number"; and upon learning that it is the one required, quickly substitutes for the calling plug then in the trunk jack, that one forming the mate to the answering plug in the calling subscriber's jack, thus giving him a connection through. This method of using the cords is called: "Using split cords", and is done to prevent the calling subscriber from hearing the connection put through to the distant office, which would tend to confuse him. This connection is supervised by the operator at the originating office in the manner already described. When the conversation is completed and the calling subscriber rings off, the originating operator goes in and says "Are you waiting?" "Are you through?" and upon hearing no response, pulls out the answering plug from the answering jack and rings on the trunk. When the operator at the distant office answers she is told to clear the connection, which she promptly does.

One great defect in the ring-down trunk system, when a large number of trunks are required between two offices, lies in the fact that it is often very difficult for an operator to secure an unoccupied trunk. Say, for example, there are ten trunks to the required exchange, and that she starts testing at the first one and finds it busy; she then passes to the next one and finds that busy, and so on. By the time she has reached the eighth jack the first one may be cleared. But if upon reaching the tenth and finding that busy, she starts over again, the first trunk may have been taken up before she again tests the jack, so that when she does it for a second time, she again finds it busy. It has been known that operators have tested over a strip of jacks in this way three or four times before an idle trunk is found.

The third case is that in which the called-for subscriber must be reached over ring-down trunks through an intermediate exchange. Call the exchange in which the call originates A; the intermediate exchange, B; and the exchange in which the required subscriber's line terminates, C. From A there are direct ring-down trunks to B, and also from B to C. But there are no direct trunks to C from A. The subscriber operator at A, having answered the call and ascertained the required number, plugs in on a trunk to B, after having tested as already described. A split cord is used. When the operator at B answers, the one at A says: "Give me a wire to C". The operator at B thereupon tests over the trunks to C in the manner already described and finding one unoccupied, plugs in and rings. Split cords are not used. When the operator at C answers she finds herself in direct communication with A and receives her request for the number required The other details of the connection are identical with those already described. When the conversation is completed, the operator at A rings on the trunk, and when the operator at B answers, directs her to clear the connection. This operator thereupon rings on the trunk to C and directs that operator to clear the connection. This is called the *tandem trunk method* and is used very much in toll business to small towns and villages. It is also used a great deal by the Long Distance Company.

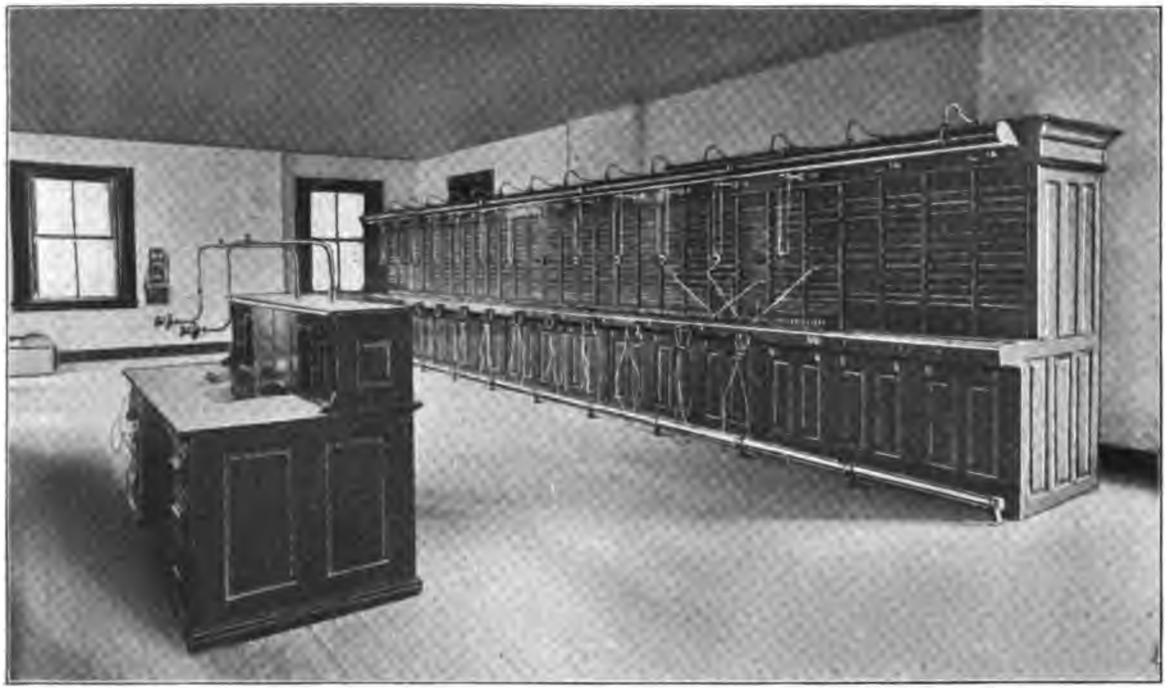
The fourth case is that which is universally used in all large cities, on account of the rapidity with which business can be handled by it. It covers the condition in which the called-for subscriber is in a distant exchange reached over a circuit trunk. The subscriber operator as usual, having answered the calling subscriber and learned his wish, throws the listening key so as to cut herself off from his line and goes in on the order key to the required exchange and asks for the number required. Suppose that the subscriber at No 750 Courtland wishes to talk to the subscriber at No 5760 38th St, the subscriber operator at Courtland St. having answered and learned the request, would go in on the order circuit to 38th St and say "5760 for Courtland St." The trunk operator at the latter exchange would then assign the trunk by calling back over the circuit "Number 5," or "Take it on Number 5," Number 5 being the trunk that she is going to use. After assigning the trunk, the trunk operator touches the ring of the multiple jack on line No 5760 to see whether or not it is in use. Assuming that the line is not busy, she pushes the plug into the jack In the meantime the A operator at Courtland St plugs into the multiple jack on trunk No. 5, using a split cord. When the incoming trunk cords are equipped with ringing keys, the trunk operator rings the called subscriber. But when these are wanting the A operator does the ringing. In either case when the called subscriber answers, the A operator assures herself that he is the right party by asking his number and then, quickly replacing the plug in the trunk jack with the mate to the one in the answering jack, completes the connection. The connection is cleared in the manner already described.

The A operator in ordering up the connection should be very careful and listen on the circuit before passing the call, to ascertain whether or not any other call is being passed at the same time. If this be neglected, she might interrupt some other call on the same circuit. Under these conditions the result would simply be confusion to the trunk operator, and both calls would have to be repeated.

Where the trunks are not equipped with disconnect signals, the same precaution should be observed by the A operator in ordering down connections, and for the same reason. Where the disconnect signals are in use, the circuit is used only for ordering up.

The fifth case is that in which the called subscriber is at a toll point and must be reached over the toll board. There are two conditions: First, where the call originates at a local office for the toll point; and, second, where the call originates at the toll point for the subscriber at the local exchange. The method of operating under the first condition is identical, whether the calling subscriber is in the same exchange as that in which the toll board is placed, or whether he is in a different exchange. It is as follows:

The subscriber having given the call to the A operator who answers him, she goes in on an order circuit to a special operator called the *Recording Operator*, and placed in the exchange with the toll board. The duty of this operator is to receive the calls for toll points and to make out tickets The call having been passed, the A operator withdraws the answering plug from the answering jack and attends to other business The recording operator, in the meanwhile, having entered on the ticket the number of the



JOHNSTOWN, PA., SWITCHBOARD.

Kellogg Switchboard and Supply Co.

calling subscriber's line and the number of the called subscriber's line at the toll point, passes the ticket to the toll operator who handles the toll trunks to this point This operator goes in on the order circuit to the exchange at which the call originated, and orders up the calling subscriber's line, which is done in the manner already described for circuit trunk operation. The toll operator plugs the answering cord into the trunk jack. While the connection over the circuit trunk is being made, the toll operator plugs the calling cord into the jack of the first unoccupied toll line, and ringing, calls the operator at the toll point. When this operator answers, the called subscriber's number is given and the connection put through in the usual way The toll operator thus handles the call throughout, noting the time during which conversation is held.

When the conversation is completed, the toll operator withdraws the plug from the local trunk jack, thus giving the disconnect signal to the trunk operator at that point, if the trunks are so equipped. If not she must go back on the circuit and order the connection cleared. She then rings on the toll line and when the operator at the distant point answers, orders the connection cleared.

From the foregoing it will be evident that from the time that the A operator, after having transmitted the call over the recording circuit, withdraws her answering plug from the answering jack, up to the time that the trunk operator takes up the calling subscriber's line, this line having no plugs in either the multiple or answering jacks, would not show busy to any other operator who tested it. If, therefore, during this period, a call comes in for the calling subscriber's line, it will be taken up by either an A or B operator as the case may be. So that when the trunk operator receives the call from the toll operator to put the connection up, she will report the line busy As a result of all this, the calling subscriber, instead of getting hold of the toll point required, gets the subscriber who is calling for him This period, during which the calling subscriber's line is unprotected, is called the *unguarded interval.*

With the introduction of the common battery system, a device was introduced with a view towards protecting the calling subscriber's line during the unguarded interval. Though common battery operating has not yet been touched on, this device will be explained here for convenience.

It consists of a specially designed cord circuit, the plug of which is introduced by the A operator, as she transmits the call over the recording circuit, into the answering jack, and is not removed until the trunk operator takes up the connection. This circuit is called the *Tone test circuit*, and is wired as shown in Fig. 254. The tip and ring of the plug are connected to battery through the retardation coil, the ring strand having a relay, of the type used on the A operator's cord circuit, in series. The shank of the plug is connected to battery through the secondary winding of a transformer, a 140-ohm resistance coil, the 15-ohm coil of a differentially wound relay, and the coil of a second supervisory relay.

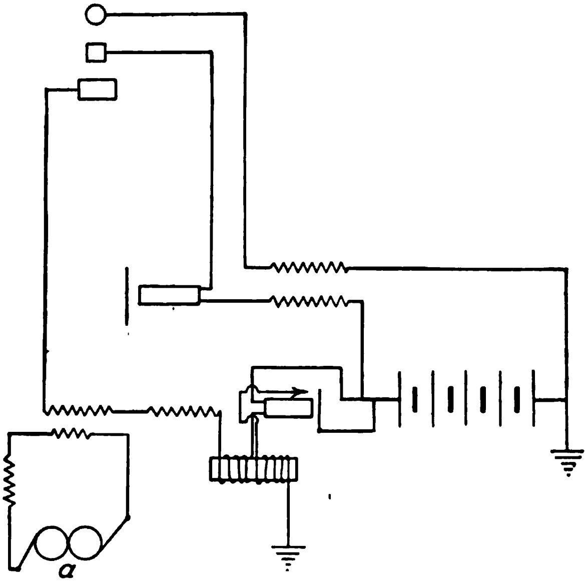


Fig. 254.

The primary winding of the transformer is connected through a 150-ohm resistance to the terminals of an alternating machine *a*.

When the A operator has received the call from the calling subscriber, and just before withdrawing the answering plug, she directs him to hang up the receiver, so that when the tone test plug is inserted, the receiver is on the hook. No current, therefore, flows through the retardation coil Current flows, however, through the 140-ohm resistance, the 15-ohm winding of the differential relay, and the coil of the 6-ohm supervisory relay, to ground through the cut-off relay on the calling subscriber's line. The 6-ohm relay becomes energized, and a path is formed through its armature and contact for the current to pass through the 130-ohm coil of the differential relay to ground. The two coils of this relay being in opposition, it is not energized. The direct current from the battery, passing through the transformer becomes alternating, and therefore, when the tone test plug is inserted in a jack, this alternating current being thrown on the ring, any operator, touching the ring to get the busy test, will, instead of getting the usual click, hear the humming noise produced thereby.

All operators are instructed to regard this "tone test" in the same light as the busy test, with the exception of the trunk operator who receives the call from the toll board. She recognizes in it the fact that the line is being held up for the toll call and introduces the trunk plug into the jack. When the trunk operator thus takes up the line, the current from the shank of the trunk plug flows along the wire attached to the rings of the jacks, till it reaches the one in which is inserted the tone test plug. From here it flows down the shank wire, through the 6-ohm relay to the common terminal of the two windings on the differential relay, thence through the 130-ohm coil to ground through the armature and contact of the 6-ohm relay.

Since the current flowing through the 15-ohm coil must still flow through the 130-ohm coil to ground, it remains the same in amount as before. The current passing through the 6-ohm relay is greater in amount and, therefore, the magnetizing effect of the 130-ohm coil becomes greater than that of the 15-ohm, hence the relay becomes energized. When this happens, the armature, touching the contact, forms a circuit through the lamp marked "Disc. Sig.", which lights. Upon seeing this the A operator removes the tone test plug. Should the calling subscriber require attention during the unguarded interval, he has only to remove the receiver from the hook, and the 120-ohm supervisory relay is energized, closing the circuit through the lamp marked "Sub. Sig." Upon seeing this lamp light, the A operator removes the tone test plug, and again answers the subscriber with the ordinary answering plug.

With the introduction of the common battery system and the resultant system of automatic signals, the methods of operating were changed in some cases. In a general way, the operators were relieved largely of the necessity of supervising calls, and the work was in many instances considerably expedited. The principal change has taken place in the work of the A operator. This should be divided into three classes:

First, calls in which the calling and called subscriber's lines are in the same exchange. Second, those in which the called subscriber's line is in a different exchange of the magneto type, reached by circuit trunks. Third, those in which the called subscriber's line is in a different exchange of the common battery type reached over circuit trunks.

The ring-down trunk operation and the toll operation are the same as already described.

Taking the first case, the operator answers the calling subscriber with the answering cord, which action automatically puts out the line lamp as has been shown previously. Upon the subscriber giving his call, the ringing plug on the same cord circuit is inserted in the called subscriber's multiple jack, after it has been tested for busy, and the subscriber rung up. When the plug is inserted into this jack, the receiver being on the hook, the supervisory lamp lights. When the called subscriber answers, this lamp is shunted out. During the conversation the two supervisory lamps are out. When the subscribers hang the receivers up after completing their conversation the supervisory lamps light, each one independent of the other. Should one of the subscribers wish to call the attention of the operator so that another call might be put through, it is done by merely moving the hook up and down, when the supervisory lamp on the cord connected with his line is flashed, thus calling the attention of the operator. When the two supervisory lamps light at the completion of the conversation, the operator clears the connection, without listening in to inquire whether the parties are through.

The second case is that in which the called subscriber's line is in a different exchange of the magneto type, reached over circuit trunks. The method of putting up the connection is identical with that already described except that split cords are not used. When the conversation is completed and the subscribers hang up, the supervisory lamp on the answering cord lights, but the supervisory signal on the calling cord remains shunted out on account of the fact that the trunk is closed through the repeating coil at the incoming end. When the first supervisory lamp lights the A operator takes down the connection, thus giving the disconnect signal to the trunk operator who clears also.

The third case is that in which the distant office is of the common battery type and reached by circuit trunks. Here the connection is put up in the manner already described. At the completion of the conversation, when the subscribers hang up, both supervisory lamps light just as if both subscribers' lines terminated in the same office. When the A operator clears out, the disconnect signal is given on the trunk and the trunk operator clears also. Before closing the subject of operating in a local exchange a word should be said relative to the duties of the trunk operator.

In one respect the duties of a trunk operator are easier to perform, than those of the subscriber operator; in another respect they are the opposite. The trunk operator does not deal with the subscriber, and is therefore free from the nervous strain consequent upon this class of work. On the other hand, in exchanges in which the percentage of trunked calls is above forty, the trunk operator is required to work more rapidly than the subscriber operator. Again, the trunk operators have to receive the calls from the subscriber operators who are always in a hurry to complete the connection. As a result they must be very careful to receive the call correctly, which is made all the more difficult from the fact that the numbers are called off very fast, and different calls come in, in rapid succession.

It often happens that two or more A operators go on the same order circuit at the same instant to order up different connections, with the result that the trunk operator is able to hear only a confused jumble. She must remain cool under these trying conditions, and be ready to put up the first intelligible order that comes. Wrong connections are sometimes put up, either because the A operator has made a mistake or because the trunk operator has heard wrongly. The result is that the A operator, after finding the mistake, has to go back on the circuit a second time, usually in a not very pleasant frame of mind, and order up the proper connection.

The frame of mind above referred to is usually vented at the trunk operator, but she must remain a perfect automaton, as far as temper is concerned, and attend strictly to business. Lastly, where the percentage of trunked calls is above 50, the trunk operators must work faster than the A operators.

Long-Distance Operating partakes of some special features which will be mentioned directly. Calls handled by the Long Distance operating department are divided into three classes. First, calls from local subscribers to long-distance points. Second, calls from long-distance points to local subscribers. Third, through calls. Calls from local subscribers to toll points are, as far as the subscriber operators are concerned, handled in the same manner as those to local toll points. The A operator, after having answered the subscriber, passes the call over a special order circuit to the receiving operator in the long-distance exchange, plugs the tone test into the subscriber's multiple and withdraws the answering plug. The receiving operator, whose duties are the same as those of the recording operator at a local toll board, makes out a ticket with the number of the calling subscriber's line, his name and the name of the party called for, together with his telephone number and the town in which it is situated. This ticket is passed to one of the recording operators, who, upon its receipt, goes in on an order circuit to the proper local exchange trunk operator and orders up the calling subscriber's number. The connection is put up in the manner already described for local toll connections, the recording operator plugging the trunk jack assigned by the local trunk operator.

She then records the number of the trunk used on the ticket, which is passed to the toll board operator who handles the lines, to the long-distance point required. The toll operator rings on one of the unused toll lines to the point required, and raises the long-distance operator at that point. This latter operator proceeds to get the called subscribers in the manner that will be described for incoming calls from toll points.

In the meantime, the calling subscriber's line, together with the trunk to the local exchanges, is held by the recording operator.

When the called subscriber has been reached by the toll line operator she plugs the answering plug into the local trunk whose number has been written on the ticket, and rings the calling subscriber, who in the meantime has hung up his telephone. Upon the subscriber again answering he finds himself in communication with the point required. When the toll line operator plugs into the trunk which is being held by the recording operator the visual on the latter's cord circuit is shown, whereupon the recording operator withdraws the plug from the trunk jack. When the conversation is completed, the visual is thrown on the toll line operator's cord by the calling subscriber hanging up. The toll line operator then releases the local trunk, and ringing on the toll line, directs the operator at the distant end to clear the connection.

Calls from toll points to local subscribers are handled as follows: It must be remembered that the call is handled in the originating exchange in the manner already described. When the toll trunk is rung upon at the distant exchange, the toll operator answers, and upon learning the number required, goes on the order circuit to the proper exchange and orders the trunk operator to put up the connection, which is done in the regular way. The toll operator plugs into the trunk assigned and the connection is complete. The connection is cleared in the manner already described.

Through calls are handled in the following manner: Suppose that a call from a toll point M comes in for a toll point N, which has to pass through the exchange in question. The operator at M rings on a toll trunk and is answered by the proper operator. After learning the details of the call, a ticket is made out with the called and calling points, and passed to the through board operator. The ticket also contains the number of the toll trunk upon which the call has come in. The through board operator selects an idle trunk to N and rings. When the operator at N answers, the details of the call are given. The through board operator then plugs the answering plug into the assigned toll trunk from M, completing the circuit. When the trunk to M is taken up at the through board, the visual is thrown on the cord circuit of the toll operator holding it, who thereupon clears out.

TELEPHONE SYSTEMS.

Under this heading is included all methods of wiring telephone circuits which possess special features, distinct from the general features of telephone wiring. Some of these systems are simple, and some of them are very complex. Some concern only the wiring of the subscriber's telephone, and some of them concern the wiring of the whole exchange. Of the vast number of telephone systems that have been introduced from time to time, only those will be considered that possess distinctive features and that have proven themselves by experience to possess decided advantages.

The origin of the telephone system seems to have been the desire to connect two or more subscribers on the same line. The first step in this direction was taken when the bridging bell was invented, as has already been explained. The system which provides for the wiring of two or more telephones to the same line is called a *Party Line System;* and a line which carries two or more telephones is called a *Party Line.*

The simplest party line system that can be devised is that in which the telephones are bridged across the same line. In Telephony, Part I, it was shown what was the limit to the number of bells that could be successfully bridged to the same line, looked at from the standpoint of the electrician. It will now be necessary to inquire what are the limits, if any, other than electrical, governing the number of telephones that can be successfully used on a party line. In this discussion the party line circuits in Telephony, Part I, should be referred to. It will be evident that when any one subscriber calls the operator, or when the operator calls any one subscriber, all the remaining subscriber telephone bells ring. Therefore, a system of signaling has to be used, in order that when the operator rings, each subscriber will know when his attention is required.

The form of signal used is a given number of rings of the bell. For instance, the first subscriber's signal will be two rings of the bell; the second, three rings; the third, four rings; the fourth, five rings, etc. Sometimes the duration of the "ring" is varied. For instance, the signal for the first subscriber may be two short rings; the second, one long and one short ring; the third, two long rings; the fourth, one short and one long ring. As the number of subscriber's telephones on the line increases, the number of signals must increase, until a point is reached at which the signals have either become so complex that the operator has difficulty in remembering them, or else they take so long to ring that a serious loss of time results, or the subscriber has difficulty in recognizing them.

Experience has shown that in large cities, and generally where the calling rate is above three per day, four telephones is all that can be bridged on one line, consistent with good results. It should be remembered that during the time that any one subscriber is using the instrument, the other subscribers cannot get service. So that the greater the number of subscribers on a line, the larger will be the interval during which any one of them will be denied the use of the line.

With this system the different stations are denoted by letters of the alphabet. The first station is denoted by A, and the second by B. With the object of selecting a letter which has a different vowel sound from either A or B, the third station is denoted by F, and the fourth by I.

The usual code of signals made use of is as follows:

> When the operator wishes to call A, two rings are used. Three rings call B; four rings, F; and five rings I. When any one of the subscribers wishes to call the operator, one ring is used.

The great disadvantage of this system lies in the fact that, when any one subscriber is wanted, the bells are rung at all the remaining stations, and also is this the case, when any one subscriber wishes to call the operator. This condition, while never pleasant, becomes a source of serious annoyance when one of the stations requires all-night service, and the others are situated in private houses.

Recognizing this point, telephone engineers set to work some time ago to devise some system whereby each station could be rung independently of the others, and the operator could be called without disturbing the remaining subscribers. It was further recognized as an additional disadvantage that when the various stations were merely bridged across the line, each subscriber was free to listen to the conversations of the others by merely lifting the receiver from the hook and holding it to the ear. Of the many systems developed to overcome the first mentioned disadvantage, the most elaborate, and at the same time the only one that overcame the second defect was that known as the *B. W. C.* system.

It is so named from the fact that these three letters represent the first letters of the names of the three inventors, Messrs. Barrett, Whittemore and Craft, at that time in the engineering department of the American Telephone and Telegraph Co. The principle upon which it worked consisted of the fact that the telephone bells were so wired that each one would respond only when the ringing current was passed through the coils in the proper direction. The system accommodated six telephones on a line. In the center of the door of the bell box was a circular opening about 1 inch in diameter. When any one of the telephones were in use a white disc with the words: "Line in Use" was automatically displayed in front of this opening on the remaining five instruments. When the receiver was hung up, the signal on the others disappeared This was called the lockout signal, and when it was displayed the hook switch was automatically held down, so that the conversation could not be listened to.

The wiring of the bells is shown in the following figures: In Fig. 255 is shown the outline of the system, illustrating the principles upon which the operation is based. Here *a* and *b* represent two sides of the line, which are known as the *a* and *b* side; *c* and *d* represent the coils of two polarized relays, the middle point being grounded. At *e* is the battery which may be connected to the line in any one of the following ways:

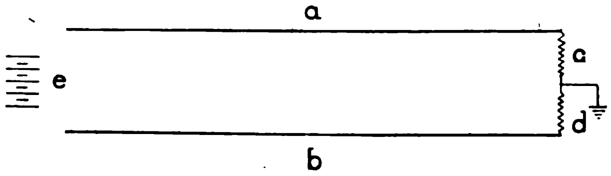


Fig. 255.

The positive pole to the *a* side of the line, and the negative pole to ground, causing the current to flow through the coil *c* to ground. The negative pole to *a* and the positive pole to ground, causing the current to flow in the same circuit, but in the opposite direction. The positive pole of the battery to the *b* side of the line and the negative to ground, causing the current to flow over the *b* side of the line and through the coil *d* to ground. The negative pole of the battery to the *b* side of the line, and the positive to ground, causing the current to flow over the same circuit, but in the opposite direction. The positive pole of the battery to the *a* side of the line and the negative to the *b* side, causing the current to flow through the two coils in series. The negative pole to the *a* side of the line and the positive to the *b* side, causing the current to flow over the same circuit, but in the opposite direction.

By properly connecting the two relay coils together and also to line, the bell may be made to respond to any one of these combinations. There are other combinations that could be made, but these six are all that are used in connection with this system.

The battery used for ringing consists of three banks of 80 volts of Leclanche battery each; the first one having the negative pole grounded, the second having the positive pole grounded, and the third connected metallic. The keyboard circuit is so wired that any one of these banks can be cut in at will.

The wiring of the bells will next be considered. From the nature of the combinations, the same bell wiring will answer for stations 1 and 3. The same wiring for stations 2 and 4 and the same for stations 5 and 6. So that only 3 different forms of bell wiring are required for six stations.

Figure 256 shows the wiring for stations 1 and 3. The bell box is equipped with three binding posts; the two outside ones being for the line and the center one for the ground connection. From the right-hand binding post the line passes down through the upper hinge of the door, to and through the right-hand 200-ohm coil, to the upper magnet coil; thence through the upper 500-ohm coil to the left-hand upper contact at the heel of the switch.

The receiver being on the hook, contact is made at this point with the switch, from which the current passes through the 200-ohm coil to the middle binding post, and thence to ground. The armature of the magnet and the contact point, when touching, form a short circuit around the upper magnet coil. When no current is following, the polarized relay attracts the armature away from the contact, so that this shunt circuit is open.

When the operator rings No. 1, the current is sent out over the *a* side of the line to the right-hand binding post, and thence to ground through the circuit already traced. The action of the current passing through the upper magnet coil, repels the armature till it touches the contact, closing the short circuit and drawing all the current from the coil. The electromagnetic field is therefore reduced to zero, and the armature, acting under the influence of the permanent field is again attracted away from the contact point. Directly this happens, current again flows through the upper coil, and the same process is repeated. In short, the armature acts like a buzzer and rings the bell.

When current is passed through from the left-hand binding post, it follows the internal wiring through the lower coil to ground. The action of this coil is to keep the armature away from the contact, thus preventing the bell from ringing. This would be the condition when No. 3 was rung. When No. 2 is rung, the current is passed through the upper coil in the opposite direction, with the result that the armature is kept away from the contact and the bell does not ring. The same conditions prevail when No. 4, No. 5 and No. 6 are rung, so that it will be seen that the bell at No. 1 responds only to its proper current. By connecting the *a* side of the line to the left-hand binding post, the bell responds to the combination for No. 3.

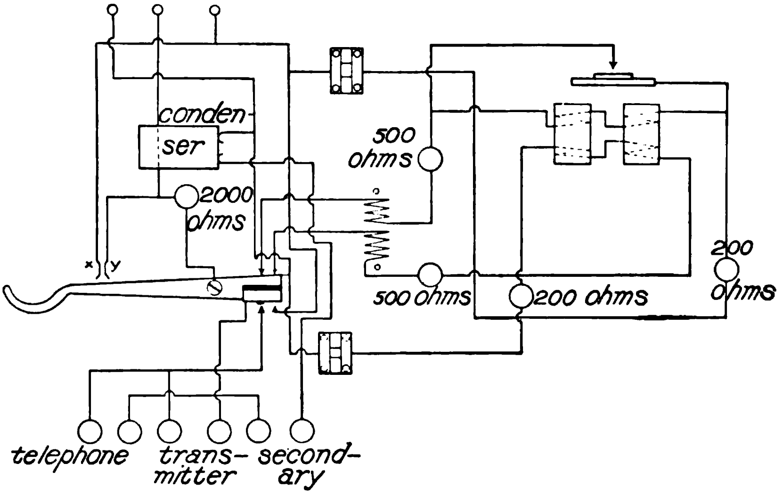


Fig. 256.

The wiring of the bell used at stations 2 and 4 is identical with that of No. 1 and No. 3, with the exception that the magnet coils are wound in the opposite direction. When the bell is used for station No. 2, the *a* side of the line is connected to the right-hand binding post, thus causing the current to flow through the upper coil, which makes the bell ring in the manner already described. Thus the bell is irresponsive to the ringing current for any other station.

In Fig. 257 is shown the wiring of the bell used for stations 5 and 6. It will be seen that the wiring is different from that already described. It will be remembered that the ringing circuit for these two stations is metallic. From the right-hand binding post, the circuit goes to the upper hinge on the door, and from thence through the upper 900-ohm coil, the right-hand 200-ohm coil to the right-hand magnet winding, through which it passes to the hook switch. Passing through the switch, it runs through the left-hand contact to the left-hand magnet coil, the left-hand 200-ohm coil, the lower 900-ohm coil, the lower hinge and out at the left-hand binding post. Current passing through the magnet coil in this direction, rings the bell in the manner already described. When the current is passed through in the opposite direction, the magnet armature is attracted and the bell does not ring.

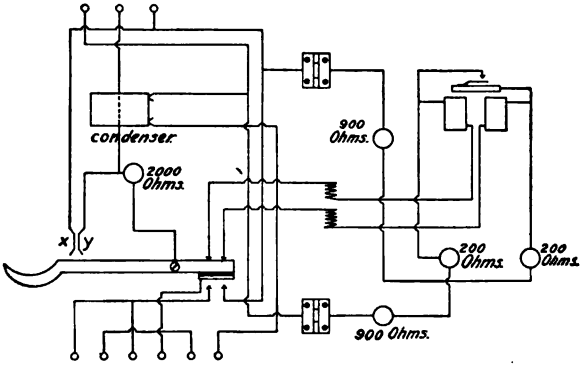


Fig. 257.

When this bell is used for station No. 6, the *a* side of the line is connected to the left-hand binding post. It will now be necessary to describe the manner in which the subscribers call the central office.

In Fig. 258 is shown the wiring of a line entering the exchange. A 4-volt battery is connected to the line drop, which is differentially wound. The current passes out through one winding of the drop, through the bell circuit at the instruments, and returning on the opposite side, passes through the other winding. The two windings of the drop being opposed to each other, the magnetic effect of one is neutralized by that of the other, so that the drop is not thrown. When the receiver is removed from the hook, however, at any one station, the hook switch in moving upward makes rubbing contact with two springs. Directly this happens, the current from the 4-volt battery passes through one side of the drop and to ground, through the middle binding post, the circuit being made through these contacts. When the hook switch reaches its highest point, this contact is again broken, and remains so during the conversation. The current passing in this way through only one winding of the drop, the differential effect is lost, and the shutter thrown. The drop is self-restoring.

In Fig. 259 is shown the wiring of the operator cord circuit, where the *a* and *b* sides of the line are shown at *a* and *b*.

The B. W. C. System has some advantages and many disadvantages, some of which were supposed to be especially strong features

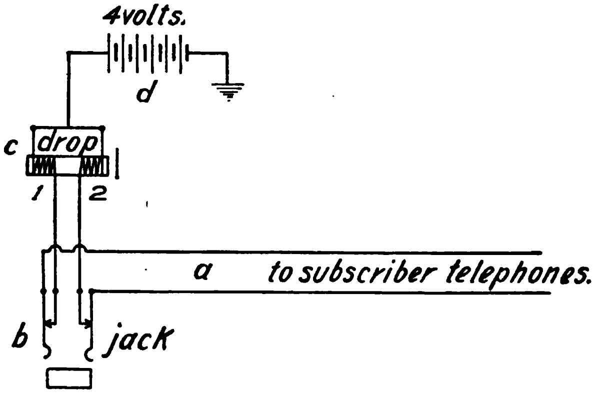


Fig. 258.

by the inventors. Among the advantages may be mentioned—First: *Selective ringing.* This feature has been shown to be the strongest one that the system possesses, and it paved the way for the inventions in this direction. Second: in small towns and villages, it gives a cheap and comparatively good service.

Among its disadvantages may be mentioned—First: The apparatus both of the telephone and switchboard are very complicated, and it is impossible to obtain inspectors with sufficient education to properly maintain either for the pay that the companies are willing to give. Second: The keyboard wiring is so complicated that only one set of keys is provided for each operator, with which she is compelled to ring on all cords. This necessarily tends to slow up the service. Third: The complicated keyboard wiring makes it impossible to provide incoming trunk sections, as with only one set of keys to a trunk operator, this would have to be used on all the trunk cords in this position, which would be prohibitive.

The switchboards are therefore made up into standard sections of from 80 to 100 lines each, and the system of operating is identical with that employed in connection with the standard switchboard. This feature limits the capacity of the office to 600 lines or 6 sections. As a result in large cities the system is not at all applicable.

Fourth: The "Lock-out" device which was supposed to be the strong point, proved to be directly the opposite, and for the following reason:

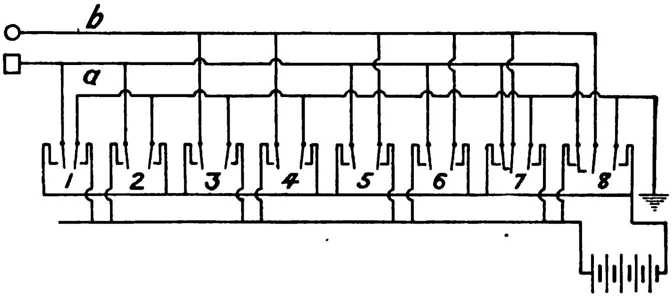


Fig. 259.

> When the lock-out signal is destroyed, the subscriber, should he desire to use the telephone, has no means of listening on the line to assure himself that the line is actually in use. He must wait until the signal disappears. His natural suspicion of corporations leads him to believe that the company has devised some scheme to prevent him using the line according to the contract, and he therefore writes a letter of complaint to that effect.

So serious a source of complaint has this become in some cases, that the lock-out device had been abandoned, and the subscribers allowed to listen in at will. Experience has shown therefore that while the *selective* feature of the system is a success, the other features are not, and as a whole the system does not seem to have a very bright future.

The selective systems to be described directly have retained the selective feature, but discarded the others. A very simple and efficient selective system is one which provides for two parties on a line, and is wired up as shown in Fig. 260. Each cord circuit both for the A operators and B operators is equipped with a special ringing key which throws the free side of a grounded alternating machine on either side of the line. This system was introduced contemporaneously with the common battery system. The diagram shows the regulation cord circuit plugged into a jack on a subscriber line, to which is wired two stations; for simplicity the line and cut-off relays are not shown, as they play no part in the operation of the system. The ringing key will be seen to be made up of two halves, each one a duplicate of the other. The ringing current generator *a*, one side of which is grounded, is wired to the outside contacts of both halves. The inner points of the right-hand half are strapped to the opposite middle contacts of the left-hand half.

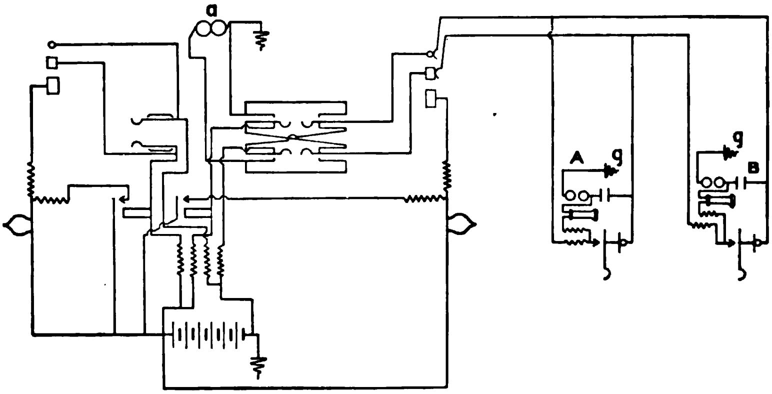
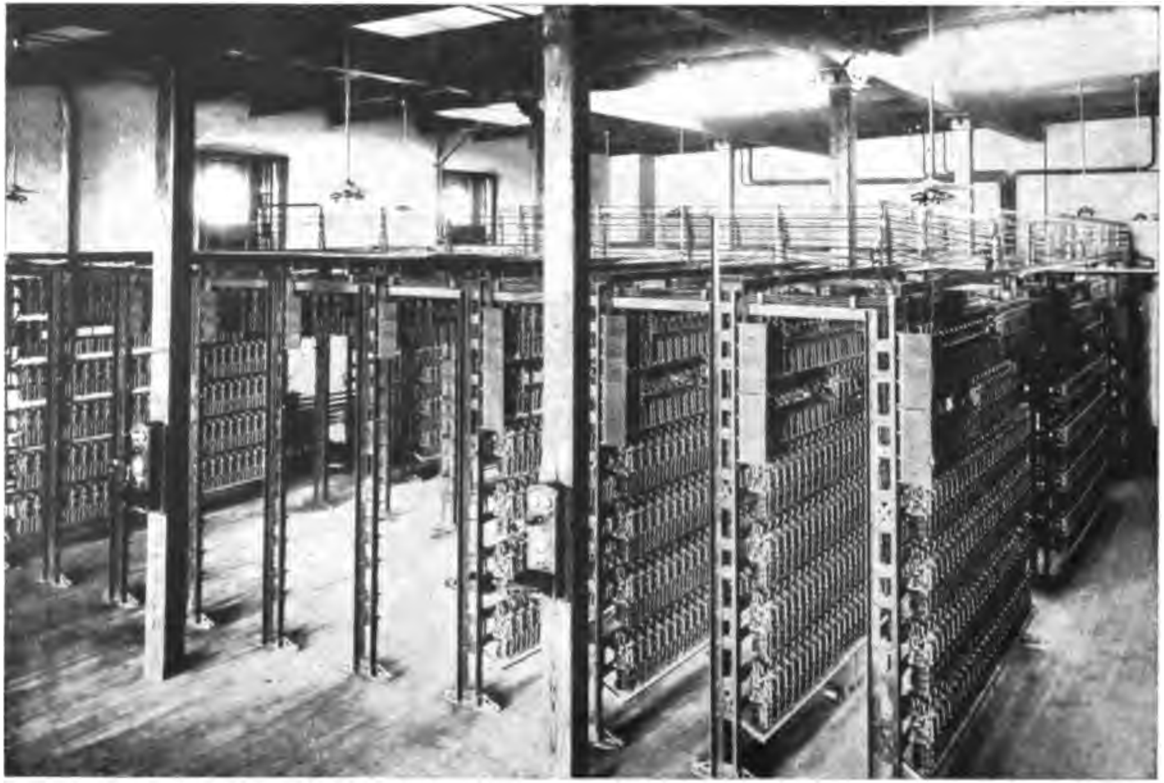


Fig. 260.

If the right-hand half of the key is used, the free side of the generator is thrown out on the ring of the plug, while if the left-hand half of the key is used, the free half is thrown out on the left tip of the plug. In both cases the opposite side of the line is grounded.

At A and B are shown two telephones, the former having the condenser wired to the ring contact line of the jack, and the latter having the condenser wired to the tip contact of the jack.

Suppose that the right-hand half of the ringing key is depressed. The free side of the generator being thrown on the ring of the plug, the current therefrom passes out on that side of the line, and upon reaching the telephone at A, flows through the condenser and bell coils to ground at *g* ringing the bell. Passing on to B the current finds an open circuit at the hook switch. If the left-hand half of



SWITCHBOARD OF AUTOMATIC EXCHANGE OF NORTHEASTERN TELEPHONE CO., PORTLAND, ME.

Automatic Electric Co.

the key is used, the current flows out on the tip side of the line, and upon reaching B, flows through the condenser and bell coils to ground at *g*, thus ringing the bell. This current upon reaching A, finds an open circuit at the hook switch. The bells are thus rung selectively.

A very good form of party selective system has been devised, which is more complicated than that already described, and operates upon a somewhat different principle. That this principle may be understood properly, it will be necessary to return for a moment to the consideration of the nature of an alternating current.

An alternating current is usually defined as one that rises from zero to a maximum in one direction, then dies away gradually to zero; it then increases gradually in the opposite direction to a maximum, after which it again gradually dies away till zero is reached. That is, if one of the terminals of an alternating current generator is regarded at the instant of the beginning of the cycle, the current will begin to flow with a gradually increasing density from the machine out on the line. After the instant of maximum flow has been passed, the current density gradually diminishes, until it dies out, but still continues to flow in the same direction. When the instant that the current density reaches zero has been passed, it starts to flow in the opposite direction, that is, from the line towards the machine, until its density has again reached a maximum, after which it dies away until it again reaches zero.

This fluctuation from zero through a maximum back to zero again, in one direction, and from zero through a maximum to zero again, in the other direction, constitutes one wave or cycle.

This wave may be regarded as made up of two impulses: The one flowing from the generator terminal to the line and the other flowing from the line towards the generator. The first is called *the positive impulse;* the second, *the negative impulse.*

The operation of this four-party selective system consists in providing a bell that will be responsive to one of these impulses and irresponsive to the others. In looking over the situation it will be seen that four combinations can be made.

First: Positive impulse on the ring of the plug with the tip grounded.
Second. Negative impulse on the ring of the plug with the tip grounded.
Third: Positive impulse on the tip of the plug with the ring grounded.
Fourth: Negative impulse on the tip of the plug with the ring grounded.

In order that these combinations can be effected, the generator must be so constructed that one brush collects positive impulses only, and the other negative impulses only. This can readily be accomplished with the usual form of magneto generator by making one half of each collector ring out of some non-conducting material such as hard rubber as shown in Fig. 261, where *bb′* represents the armature coil. Regarding the side *b*, assume that the direction of the magnetic flux and the direction of rotation cause the current to flow in the direction of the arrow; then the direction of the flow in the side *b′* will be as indicated by the other arrow. Then in the position shown, the left-hand brush will be positive and the right-hand one negative. If the collector rings were made up wholly of conducting material, then when the armature rotates through 90° the right-hand brush will become positive and the left-hand negative. But if one half of each ring is made of hard rubber as shown by the shaded portions on the diagram, then when the armature coil has revolved far enough to change the direction of current flow in the side *b*, the brush will be resting upon the insulated portion and no current will flow through it. Similarly, when the direction of current flow in the side *b′* changes, the left-hand brush will be resting on the insulating portion. As a result the left-hand brush will receive positive impulses only, while the right-hand brush will receive nothing but negative impulses. The ringing key used in connection with this system is so arranged that the positive or negative terminal is connected to either side of the line while the opposite side is grounded. The wiring of the operator's cord circuit is shown in Fig. 262.

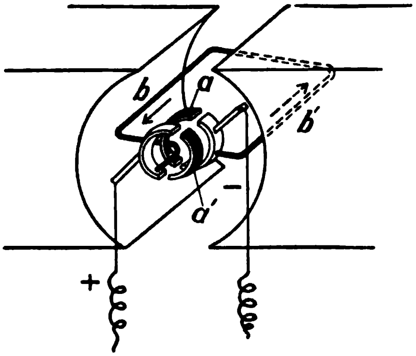


Fig. 261.

AUTOMATIC SYSTEMS.

Under this heading is included all the systems whereby the subscriber is enabled to provide the proper connections without the assistance of an operator. Systems of this type have been largely used for some years for what is known as *house service*, which means interconnection between offices in the same building or the like. Automatic systems have also been devised for general use. In this connection the exchange is equipped with the automatic switching device, and no operators are required. These latter systems do not give much promise, as the cost of the installation is away beyond that of the ordinary type of switchboards; while the cost of maintenance is also excessive. For example, the cost of a 50-line switchboard installed with auxiliary apparatus is about $500.00, while the cost of an automatic switchboard of the same capacity is about $3,000.00. The annual charge against an exchange, including operator's salaries, heat, supplies, maintenance, but not rent, is about $1,000.00. The automatic system has not been in use long enough to enable one to get a very correct idea of the cost of maintenance. But experience, shows that it is fully equal to the above-mentioned figure, and may, in some cases, even exceed that. For house service, however, the automatic system is very successful and is used extensively.

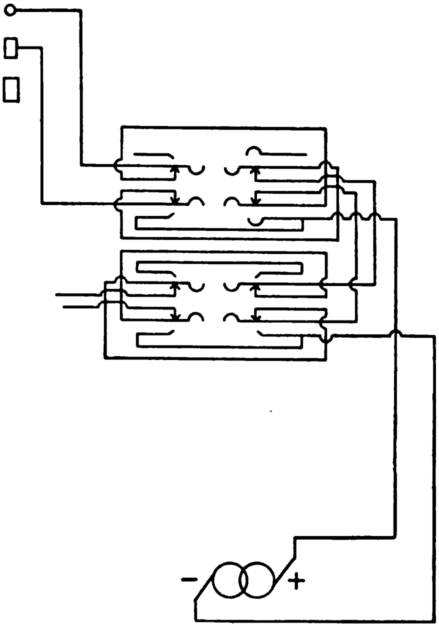


Fig. 262.

Among the best adapted systems of this class is the one which is shown in Fig. 263. Here are shown four instruments connected together. The wiring of the telephone is the same as that of those designed for general use. Each instrument is equipped with a series bell and magneto generator. One side of all the instruments is wired to a common return wire, in addition to which there extends between each one and its fellows, the same number of wires as there are instruments, and each one terminates in the contact of the switch placed at each station. These contacts are arranged on the circumference of a circle, over which the switch lever passes. The heel of the switch lever is permanently connected to the opposite terminal of the instrument. These contact points are numbered to correspond with the number of the station with which they connect. When the telephone is not in use, the switch lever should be left on the contact whose number corresponds with that of the instrument.

Referring to the figure. Suppose that station No. 1 wishes to call station No. 2. The switch lever at station No. 1 is moved from contact No. 1 to contact No 2 and the generator turned.

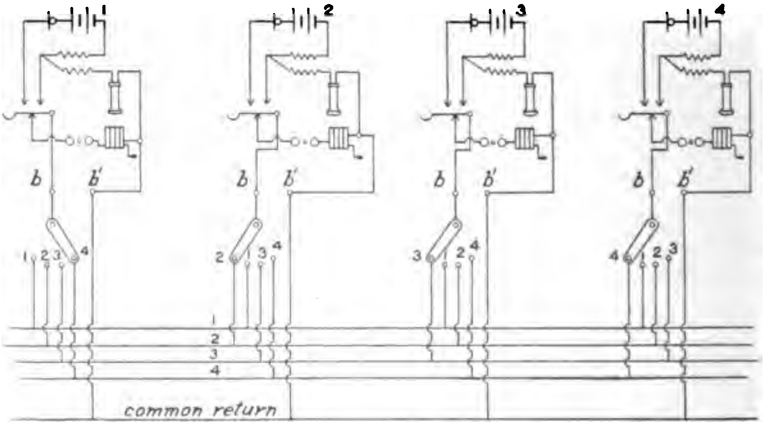


Fig. 263.

The ringing current flows from the generator at No. 1, along the common return to station No. 2, thence through the generator and bell to the opposite side of the lever. Passing through the switch lever which rests on contract point No. 2, the current flows along wire No. 2 to the No. 2 contact at switch No. 1, and through the switch lever through the bell back to the generator. Transmission is carried on over the same circuit. If the party at No. 1 desires to communicate with station No. 3, the switch lever is moved to contact No. 3 and the party rung up. The circuit is made up of the common return wire to station No. 3, thence through the instrument to the switch lever. Passing through the switch lever to contact No. 3, it follows the line to contact No. 3 at station No. 1, from which it passes through the switch lever to the opposite side of the telephone. By the same method each one of the other stations can call any of the others. In the figure No. 1 is in position to call up No. 4.

From the nature of the wiring, it will be seen that when a telephone is not in use, the switch lever must be always left on the contact whose number corresponds to that of the station. That is, at station No. 1, the switch lever must be left on contact No. 1, while the instrument is not in use; at station No. 2 the switch lever must be left on No. 2, etc.

Consider what would happen if this were not done. Suppose that through carelessness or other cause, the switch at No. 1 were left on contact No. 4, and that station No. 4 wished to call up No. 1. The party at No. 4 would move the switch lever to contact No. 1 and ring, but under these conditions the circuit would be open at the contact at station No. 1, so that this station could not be called. It is, however, possible to arrange the wiring so that a station will get a ring even if his switch is not on the home station point, although it must be placed there before conversation can be carried on.

One defect of this system lies in the contact buttons of the switches. Being exposed to the air, they are apt to become covered with dust, and thereby the electrical contact is made very poor, in fact, it sometimes happens that the dirt accumulation is so thick as to prevent contact from being made at all. To overcome this defect, the switches are sometimes replaced by jacks and plugs. Under these conditions each station is equipped with a small box containing the same number of jacks as there are stations. Each jack is numbered to correspond to the number of the station to which it is wired. To call, the plug is inserted into the proper jack and the generator turned. When the telephone is not in use the plug is left in the jack corresponding to the number of the station. This jack is called the home jack.

Various devices have been brought forward from time to time with the object of doing away with the necessity of returning the switch to the home contact, or placing the plug in the home jack. The most successful of these is the one put forth by the Holtzer-

Cabot Company, of Boston, Mass. The feature of this system consists of an automatic mechanism which causes the switch lever to return to the home button or contact, when the receiver is hung up. In addition it also makes use of a common signaling wire. The mechanism of the apparatus is shown in Fig. 264. The hook switch and the switching mechanism are contained in a box, on the outside of the door of which is placed the switch lever and the contact buttons. Outside of the latter and insulated from them is a metal arc-shaped piece, which the end of the lever does not normally touch; but by pressing the lever, electrical contact can be made between the two. To this arc is connected the common call wire. Fastened to the shaft of the switch lever, and placed inside of the box is a ratchet wheel *a* into which fits a pawl *b*, held in place by a spiral spring *c*. The hook switch is shown at *d* and has its heel equipped with a hard steel dog *e* pivoted at *f*. This dog is brought back by the spiral spring *g* to the position shown. The ratchet wheel *a* is, when left free, rotated clockwise by a coiled spring (not shown).

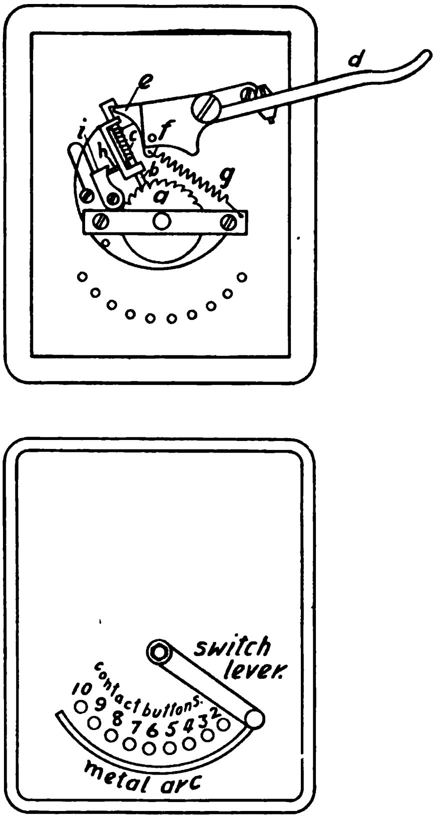


Fig. 264.

The receiver being on the hook, the party wishing to call moves the lever till it touches the proper contact button, and pressing it till it makes contact with the arc, calls the desired party. As the lever is rotated so is the ratchet wheel, and the pawl retains it in the proper position. When the receiver is hung up again, as the heel of the switch moves up, the dog *e* engages in a notch at its top, and lifts it clear off the ratchet teeth. The ratchet wheel thus being set free is rotated under the action of the coiled spring towards the home position. Since the dog *e* engages the notch in the pawl only momentarily, as the heel of the switch passes upward, it would slip back and engage the ratchet teeth before the wheel had returned to the home position, were not some means taken to prevent it. To this end the pawl is provided with a pin *h*, which as it passes upward engages with a second dog *i*, preventing it from again returning to its downward position. This second dog is tripped by the ratchet wheel just as it reaches the home position, allowing the pawl to fall at the proper time.

MAINTENANCE.

General Remarks. The general plan of organization followed by the majority of the telephone companies at the present time, calls for the following departments:

The *Engineering Department*, whose business it is to design the plant to be used and to supervise its construction. The *Construction Department*, which has to do with the building of the plant. The *Traffic Department*, which has to do with the operation of the plant. The *Maintenance Department*, which has to do with keeping the plant in condition necessary for its proper operation. The *Supply Department*, which is concerned with the feeding of the plant.

There are two other departments which are found to be necessary in all large companies, and they are, the *Contract Department* and the *Right of Way Department*. The functions of these two latter are indicated by their titles. It is not the purpose of this article to discuss the subject of organization, but to prefix a treatise on the subject of maintenance, by a few general remarks on the duties performed by each department of a well organized company.

THE MAINTENANCE DEPARTMENT.

The *Maintenance Department* has been defined as that which has to do with the keeping of the plant in such shape that it can be properly operated. It will now be necessary to learn the method of organization and the nature of the work to be performed, in order that the plant may be so maintained.

The subject of maintenance is best studied under the following heads: *Exchange Maintenance*, *Line Maintenance*, and *Station Maintenance*. The first, as its name indicates, treats of the maintenance of the central office apparatus; the second treats of the maintenance of the line; while the third relates to the maintenance of the subscriber telephone.

It should be mentioned here in passing that line maintenance does not include the maintenance of cables; this work being done by the construction department for reasons which it is not necessary to state.

The subject of central office maintenance will be taken up first, and in this connection it will be learned how and where the trouble is first reported; to whom the trouble reports are sent; how they are recorded and the trouble tested, and what steps are necessary to be taken to clear the trouble, whether it be in the exchange, on the line or at the station.

METHOD OF REPORTING TROUBLE.

From the fact that the traffic department operates the plant, it would be the first to note any defect in its condition, and so all trouble reports originate in this department. Besides the cases of actual trouble, there is a second class of irregularity called "Don't Answer", which, as the name indicates, refers to all cases in which the operator is unable to make the called subscriber answer the telephone. These "Don't Answers", as they are called, are referred to the monitor in the exchange into which the called subscriber's telephone line runs. If after trial this official is unable to obtain a response from the called party, the case is referred, together with the actual trouble, to the maintenance department. A record of all trouble reported is kept by the traffic department.

ORGANIZATION OF MAINTENANCE DEPARTMENT.

The method of organization of the maintenance department will depend largely on the nature of the territory to be covered and the volume of business to be handled. A typical system of organization will be given, however, which will cover all the essential features.

The department is presided over by a superintendent, who in addition to the necessary clerical force, should have the following lieutenants: A district inspector, a foreman of instrument setters, and a foreman of inspectors. Reporting to the district inspector, there should be in each exchange a wire chief, whose duty it is to test all trouble reported, to direct the force of men who clear the trouble, and to see that the central office is kept in proper condition. The size and nature of the force reporting to the wire chief will depend on the size of the exchange, and the extent of territory covered by the district. In the large exchange, it will be found necessary to provide an assistant wire chief in addition to the inside trouble men. Where there is an assistant wire chief, he is the man who does the actual testing; the wire chief having enough to occupy his time in the general supervision and care of the office.

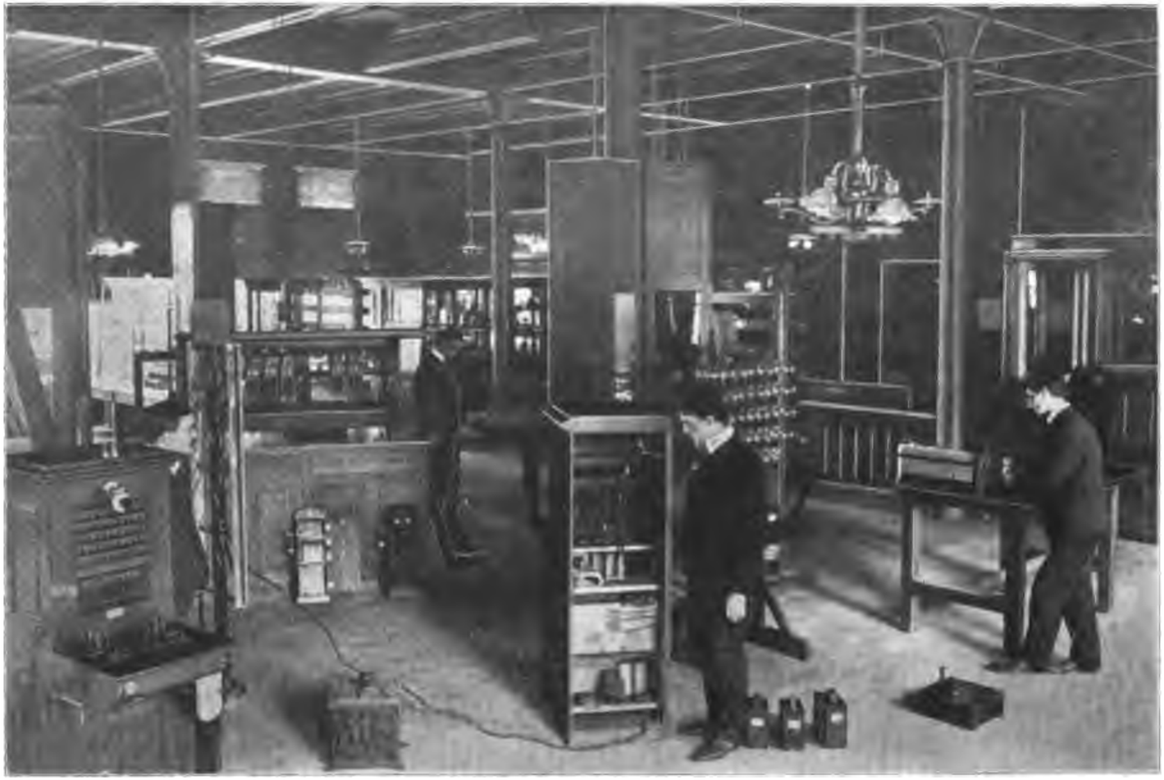
The duty of the inside trouble men is to clear whatever trouble occurs to the switchboard and central office apparatus. The requisite number of these men will depend altogether on the size of the office and the volume of business handled. For the purpose of clearing line trouble a force of outside trouble men is needed. These men must be linemen, and capable of handling all trouble that occurs to the open-wire lines.

The instrument or subscriber station trouble is handled by a force of inspectors who are familiar with the method of operation of the various telephone instruments, and are therefore able to keep them in proper working order.

The usual arrangement is to have the outside trouble men, together with the central office force, report to the wire chief, while the inspectors report to their foreman This plan is considered to be the best practice, but is not always followed.

The Foreman of Inspectors has under him his force of inspectors, who keep constant watch over the subscriber stations. The usual method is to divide the territory into "Routes", assigning an inspector to each route. The inspector visits constantly the telephones on his route, taking each in its turn, repairing whatever defects he notices, and keeping them in first-class general working order. He is also called upon from time to time, as occasion arises, to clear whatever trouble may occur to the telephones under his jurisdiction. To this end he is required to keep in constant touch with the wire chief of the exchange, within the district of which his route lies. In cases where Leclanche batteries are used, he is required to carry in his satchel, in addition to the necessary tools, a supply of sal ammoniac and battery zincs. Where Fuller batteries are used, he carries in connection therewith only a small bottle of mercury.

The work of renewing the batteries is here delegated to a separate force of "battery men," who are provided with wagons, carrying battery acid, zincs, carbons, and jars, and who are assigned to routes similar to but larger than those assigned to the inspectors. These men are also required to clear special battery troubles, and are therefore required to report regularly to some one delegated to receive reports of this nature. Where the battery route lies wholly within one exchange district, the battery man reports to the wire chief. Where the route lies within the districts of more than one exchange, the wire chiefs of these exchanges report their battery troubles to an assistant to the foreman of inspectors, and the battery men are required to keep in touch with this official. Usually the battery men come under the jurisdiction of the foreman of inspectors Where the work is very heavy, however, a special foreman is assigned to look after this work. Where the common battery system is used, the battery renewal work is eliminated.



TELEPHONE LABORATORY.

Armour Institute of Technology.

TELEPHONY.

PART VI.

MAINTENANCE.—(Continued.)

The Foreman of Instrument Setters has under his direction the force of men who equip the subscriber stations with the necessary telephones. Their work consists, in addition to placing new telephones, of renewing and replacing working telephones, upon the subscribers changing their addresses. Upon the completion of such work they are required to call the wire chief of the district in which this work is done, in order to keep him posted and assist him in making whatever tests he deems necessary. The organization of the maintenance department having thus been treated in outline, it will now be necessary to take up each sub-department in detail, and follow closely the work performed. It will be assumed that the student is familiar with the nature of a modern telephone plant, both in regard to circuits and apparatus used. Wherever it becomes necessary to refer to circuits or apparatus designed for maintenance purposes, these will be given in fullest detail.

The District Inspector. This official is the one to whom the wire chiefs report. He should be a thorough maintenance man, and is usually graduated from the position of wire chief. He is responsible for the condition of the exchanges and the lines. He receives monthly reports from each wire chief, which show the number of troubles reported; the number of such cases in which actual trouble was found upon testing; the number of such cases which were found to be without actual trouble upon testing; the number of "Don't Answers" reported, and the number of these reports that proved upon test to be cases of actual trouble. A report is also sent in from each exchange showing the number of troubles cleared by each trouble man, and the average time occupied in so doing:

These reports form a basis for a monthly report which the *District Inspector* is required to forward to the *Superintendent.* The reports above referred to, are useful not only in determining the character of the employes' work, but also in determining which portion of the circuit or apparatus is most apt to get into trouble. From these reports also, the requisite information is obtained for determining the size of force necessary for the proper maintenance of the plant. It is in the analysis of these reports that the experience of the district inspector becomes useful, in rendering him able to compare the actual conditions with those which should obtain in an ideal plant. In addition to the handling of reports, the district inspector is called upon to transmit all necessary orders to the wire chiefs, and to see that they are properly carried out. The duty of ordering supplies, and extra apparatus for maintenance purposes also devolves upon him, and he is the sole judge of the amount of such material necessary to be kept on hand

The Wire Chief. The duties of the district inspector having been described, it now becomes necessary to take up those of the man who has in hand the actual maintenance of the plant, the *Wire Chief.* He is the officer on the firing line as it were, and he is directly responsible for the condition of the district. Everything depends on the wire chief. If this official is of the right caliber, he will see to it that he has the right sort of assistance, and that his force, both within the exchange and without, attend properly to their duties, under his direction. He should be a man who is not only thoroughly familiar with the details of the plant, both within and without the exchange, but also with the habits of the men of the class whom he has to direct. He must be able to do all the necessary testing with the utmost dispatch, and to properly direct the men in clearing trouble. An exchange maintenance force with a poor wire chief is like a ship without a rudder.

The following routine business passes through the wire chief's hands:

Testing and clearing all cases of trouble within the exchange district. Giving the construction gangs and the instrument setters, O.K. reports when their work is properly done. Receiving the reports of the inspectors and battery men. Supervising the renewal of lines that have been discontinued.

At this point it will be well to follow the course of some of the orders which reach the wire chief for final action. The order for a new line will be taken as an example.

The new-line orders are made out in the *General Superintendent's* office and are then sent to the construction department for the proper assignment of conductors. The conductor assignment having been placed upon the order, it is then sent to the maintenance department, after the requisite information has been taken off to enable the construction gang to build the line. Upon its receipt at the maintenance-department office a duplicate is made out for the foreman of instrument setters, the original being sent to the wire chief, within whose district the new line is to lie. Upon receipt of this order the wire chief has the cross connection properly run on the main distributing frame, and sends the order to the exchange manager for his information, and for the purpose of enabling him to enter upon the order the answering jack assignment. The order is then returned to the wire chief, who has the proper cross connection made on the intermediate distributing frame, and where the magneto system is used, the line drop is placed with the new line number and whatever symbol is used to denote the particular class of service. Where the common battery system is used, in addition to running the cross-connection at the intermediate jack, the proper number plate must be placed over the answering jack, and a lamp cap, marked to denote the particular class of service, placed over the line lamp.

In the meantime, when the construction gang which has been busy building the line, finishes its work, the wire chief is called and a thorough test made to determine whether or not the proper conductors have been used, and of proper continuity and insulation resistance. The construction foreman is then given an O.K., and this is recorded on the order, together with the time of day and the name of the foreman. The line is now ready for the instrument setter, and when he finishes his work he calls the wire chief and the line is given a complete test.

Nature of Tests and Testing Apparatus. The nature of the tests made, and the nature of the testing apparatus used in the routine work of central office maintenance, will now be described.

Leaving out of consideration for the present the subscriber station, the troubles to be cleared by the maintenance force are classified under the following heads:

1. Crosses, in which one or both sides of two metallic circuits come into electrical contact, so that conversation on one can be heard on the other.
2. Opens, in which one or both sides of a circuit become electrically discontinuous.
3. Short circuits, in which one side of a circuit comes in contact with the other side, thereby cutting out or isolating the terminal apparatus.
4. Grounds, in which one or both sides of a circuit form electrical contact with the earth, rendering the line more or less noisy, and the conversation indistinct.

The introduction of the common battery system, has introduced a fifth class of trouble called "low insulation", which refers to the condition where the insulation of the line has become so low that, while it does not interfere with conversation, it prevents the proper working of the line and supervisory signals.

With the magneto system, the following conditions obtain on the subscriber—sending, ring-down, and common trunks. A metallic circuit closed at the distant end through the bell at the subscriber telephone, or drop in the case of a trunk, and at the exchange end, closed through a drop in the first and last named circuits, or standing open through the multiple in the case of a sending ring-down trunk. All circuit trunks, whether incoming or outgoing, are closed through repeating coils at both exchanges, so that under normal conditions all circuits show closed towards the foreign end, and all circuits except sending circuit trunks and sending ring-down trunks, show open towards the home exchange, if the test is made inside of the repeating coil. With the common battery system, on the other hand, the subscriber lines test open towards the telephone, or distant end, and open towards the exchange when the cut-off relay is energized. The outgoing ring-down trunks show closed as before, as do the outgoing circuit trunks to magneto offices. The outgoing trunks to relay offices, on the other hand, show open under normal conditions, owing to the presence of the condenser cut into the repeating coil at the distant end. All circuits except the incoming ring-down trunks, if there be any, show closed towards the home exchange, if the test is made inside of the repeating coil.

The tests made by the wire chief are by no means as elaborate as those used by the cable maintenance department in locating faults. They are such as can be made very rapidly, and yet are sufficiently accurate to enable the wire chief to determine where to look for the trouble. Before going into the details it will be necessary to consider the general plan followed in locating trouble; after which the detail tests, with the apparatus used for both the magneto and common battery system, will be followed out.

When a trouble is reported to the wire chief, his first duty is to determine whether it lies within the exchange or without. Any trouble which is located on the main distributing frame, or in the office wiring between this point and the last section of switchboard, is said to be an inside trouble. But if it is located in the wiring anywhere between the main frame and the subscriber station, it is said to be outside trouble. Some troubles are of such a nature that their location can be determined without any special test, while others necessitate a succession of tests before the requisite knowledge is determined. A trouble being reported, the line in question is first taken up at the main frame and a test made between this point and the switchboard. If this portion of the line is found to be in good working order, a test is then made between the main rack and the subscriber station, and the trouble will be found to be located in this portion of the wiring. The portion of the line in which the trouble is located, must next be determined, and the method of so doing will be described later. Should the trouble be located in the exchange wiring, the line is again tested between the main and intermediate frames. If this portion proves to be in proper condition, it is tested between the intermediate frame and the first section of switchboard, then between the first and last sections of switchboard, the process being repeated until the defective portion has been found.

The apparatus used for testing in connection with the common battery system differs materially from that used with the magneto system, and the nature of the tests used differs also, on account of the difference in the natures of the circuits used in the two systems. With the magneto system all circuits, with the exception of the incoming end of circuit trunks, are normally closed. With the common battery system on the other hand, all circuits test normally open. Again, the presence of current on the line continually, in the case of the common battery system, gives an additional means of testing, which is not present in the magneto system.

In connection with the magneto system, the circuit shown in Fig. 265 is the one made use of by the wire chief. It consists of the following: A plug *a* is wired to a ringing key *b*, the generator being shown at *c*. The listening key is seen at *d*, the wires leading to the wire chief's telephone being shown at *k*. At *e* is seen a battery of 3 Fuller cells, which is wired to a telegraph relay *f*, so that when the plug *a* is inserted into a closed line, current flows through the relay, energizing it and drawing the armature *i* up against the contact point *h*, closing the auxiliary circuit containing the battery and the telegraph sounder *g*. The sounder is used to intensify the noise made by the closing of the relay, thus giving the wire chief an oral test. At *l* is shown another plug wired to a reversing key *m* which is grounded at *n*, so that this ground can be thrown on either the tip or ring, as desired. This circuit is used in testing crosses, as will be explained later.

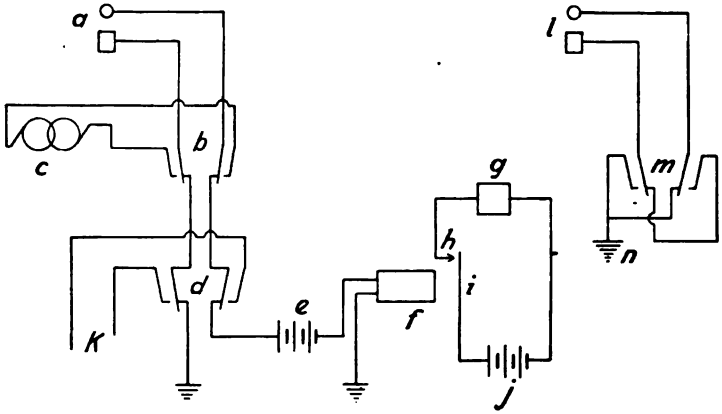


Fig. 265.

This circuit is placed on the wire chief's desk, which is wired like the operator's keyboard. A second class of circuits must now be provided for use in enabling the wire chief to get access to the line to be tested. These latter circuits are called "the wire chief's trunks". The following trunks are usually provided: One or more to the first section of switchboard; one or more to the last section; one or more to the main distributing frame, and one to each one of the incoming trunk positions. The wire chief's desk is lastly equipped with lines to the switchboard for use in ordinary conversation.

In Fig. 266 is shown the wiring of a line to first and last sections of switchboard. It consists of a cord and plug *a*, placed on the switchboard and wired to a jack *b* placed on the wire chief's desk, there being no drops placed at either end.

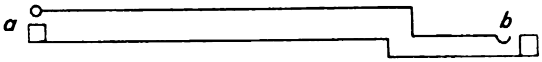


Fig. 266.

In Fig. 267 is shown the wiring of a line to the trunk positions. It consists of a jack *a* placed in the multiple, and wired to a jack *b* placed at the wire chief's desk.

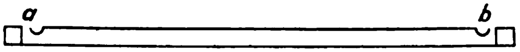


Fig. 267.

In Fig. 268 is shown the wiring of a line to the main distributing board. It is rather more complicated than any of the others, and is arranged to cut off one part of the line while the other part is being tested. Two special jacks *d* and *d'* are placed on the wire chief's desk. Their sleeves *e* and *e'* are not connected. The spring 5 of *d*, is wired through the contact points to the spring 7 of *d'*; and the spring 6 of *d* is similarly wired to the spring 8 of *d'*. At *a* and *a'* are shown two hard rubber plugs with one face bevelled. The face of each of these plugs is equipped with a German silver clip *b* and *b'*, while the two bevelled faces are equipped with two German silver clips *c* and *c'*. Following out the circuits, it will be seen that the spring 5 is wired to *b*; the spring 6 to *b'*; the

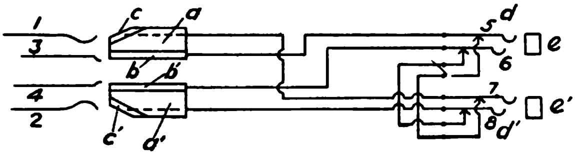


Fig. 268.

spring 7 to *c*, and the spring 8 to *c'*. At 1 and 2 are shown the heat coil springs of a line on the main distributing frame; and at 3 and 4 are shown the ground springs. The heat coils are supposed to occupy the spaces 1 and 3, and 2 and 4; while the carbon plate arresters fit in between 3 and 4.

When a line is to be tested, the heat coils are removed from the springs, and the plug *a* is inserted between 1 and 3, and the plug *a'* between 2 and 4. When in position the spring 1 makes contact with the clip *c*, and the spring 3 makes contact with the clip *b*. Turning to the other plug, the clip *b'* makes contact with the spring 4, and the spring 2 with the clip *c'*. Under these conditions, the line coming in from outside passes from the spring 3 to the clip *b*, thence to the jack spring 5, and through the contacts to the jack spring 7. Thence to the clip *c* and the heat coil spring 1 to the switchboard. Returning to the heat coil spring 2, it passes through the clip *c'* to the jack spring 8, thence through the contacts to the jack spring 6, to the clip *b'*, the ground spring 4 and out. If a plug be inserted into the jack *d*, the contacts at 5 and 6 being broken, the switchboard end of the line is cut off, and communication is established with the outside portion. On the other hand, when a plug is inserted into the jack *d'*, the contacts at 7 and 8 are broken, the outside end of the line is cut off and communication is established with the switchboard. In addition to the above circuits, the wire chief's desk is equipped with an order circuit to the first section, and one to the last section of the switchboard and one to each incoming trunk operator.

The next point to be considered is the method adopted by the wire chief for testing the troubles that are reported to him. In this connection, it will be well to go over the nature of the troubles that he may be called upon to test.

TESTING FOR TROUBLES.

Troubles may be divided into three classes:

(1) Those situated in the wiring of the line, whether within the exchange or without.

(2) Those in the apparatus of the exchange, such as the drop or jack.

(3) Those in the apparatus of the subscriber telephone.

The first class are called *wiring troubles*, the second, *apparatus troubles*, and the third, *station troubles*. The wiring troubles are the only ones which the wire chief is able to test out with the apparatus described. Wiring troubles are divided into five classes: (*a*) Opens; (*b*) Grounds; (*c*) Short circuits; (*d*) Crosses; (*e*) Escapes. Opens are caused by a parting of the wire on one or both sides of the line. Grounds are caused by one or both sides of the line coming in electrical contact with the earth. Short circuits are caused by the two sides of a circuit coming in electrical contact. Crosses are caused by one or both sides of one circuit coming in electrical contact with one or both sides of another circuit. Escapes are nothing more than high resistance grounds.

Opens are detected by the fact that the subscriber cannot be rung over the line. If a long line made up largely of cable conductors be open on one side it is often possible to carry on conversation over it. But the alternating current used for ringing is not of sufficient frequency to pass the gap, therefore the signal cannot be transmitted.

Grounds are detected by the fact that the line becomes noisy, and when the ground is heavy on both sides, it amounts to a short circuit and the subscriber is cut off from all communication whatsoever.

Short circuits are detected by the subscriber being thus cut off.

Crosses between two lines are detected by the fact that a person conversing over one line can be heard on the other line

Escapes are detected by the presence of noise, when the line is connected to a long-distance trunk.

When an *open* is reported to the wire chief, his first duty is to determine whether or not it is situated outside of the exchange. To this end he removes the heat coils from the arrester springs and inserts the plugs *a* and *a'*, Fig. 268, in the manner already shown. The plug *a* of the testing circuit, Fig. 265, is inserted into the jack *d*, Fig. 268, thus cutting off the switchboard end of the line. If the open is located outside of the exchange, the relay *f*, Fig. 265, will not be energized when the plug is so inserted; for the circuit being open, no current can flow through it. If the open is located within the exchange, on the other hand, the relay will be energized when the plug is so inserted, and the click of the sounder will be heard. If this latter condition obtains, the plug is then inserted into the jack *d'*, Fig. 268, thus cutting off the outside portion of the line, and establishing communication with the switchboard. The presence of an open is detected in the same manner as before. The plugs *a* and *a'*, Fig. 268, are then removed, and the heat coils are replaced, care being taken to test both of them for opens before doing so. The wire chief then goes in on the order wire to the operator at the last position of switchboard, and directs her to place one of the plugs *a*, Fig. 266, into the multiple jack of the line in question. The test plug is then introduced into the jack *b*, Fig. 266, and an inside man is directed to short circuit the line on the main distributing frame with his pliers. Should the line show open still it is cleared at the last section, and the operator at the first section is directed to plug it up, using a similar circuit, while the short circuit is maintained on the main rack. Should the line show closed from the first section, the open is located in the switchboard wiring somewhere between the first and last section.

Assuming that such is the case, the inside man removes the short circuit from the main rack, and going to the switchboard, sticks a plug, the ring and tip of which are short circuited, and which he carries in his pocket for the purpose, into the multiple jack on the second position. If the line then shows closed, he removes the plug and places it in the multiple jack on the third position. He continues this process until the line again shows open. When this occurs, he knows that the open is located between the section where it last showed closed and the section where it first showed open.

Again, if when the line is tested from the first section of board, the short circuit being placed on the main frame, and it shows open, it will prove that the trouble is located between these two points. Under these conditions, the inside man is directed to short circuit the line at the intermediate distributing board, and if upon so doing, it tests short circuited, the open will be located between the intermediate and main distributing boards. This method of testing will be understood more easily by referring to Fig. 269, which shows in outline, the circuit in question from the main frame to the last section of switchboard. Suppose that *a* and *b* represent the main and intermediate frames respectively, and *c*, *d*, *e*, *f*, *g*, and *h*, the multiple jacks. Let *x* be the point where the line is open; let 1 and 2 be the tip and ring of the testing circuit, which is shown much simplified. The test battery is at *i* and the relay at *j*. With the conditions shown, if the line be short circuited at the main frame, it will nevertheless test open as one side is open at *x*. If now the test plug be placed in the jack *c*, the line will test short circuited, because the open is beyond the testing point. Leaving the testing plug at *c*, removing the short circuit from *a*, and putting a short circuiting plug in *d*, the line will again show closed, as it will if the plug be placed at *e*. But when the plug is placed at *f*, the line will test open, because the open lies between the testing point and the place where the line is short circuited. The test could also be made by placing the plug at *j*, removing the short circuit from *a*, and placing the short circuiting plug successively at *g*, *f*, and *e*. In this case the open lies between the jack where the line first showed open and the last jack, where it showed closed.

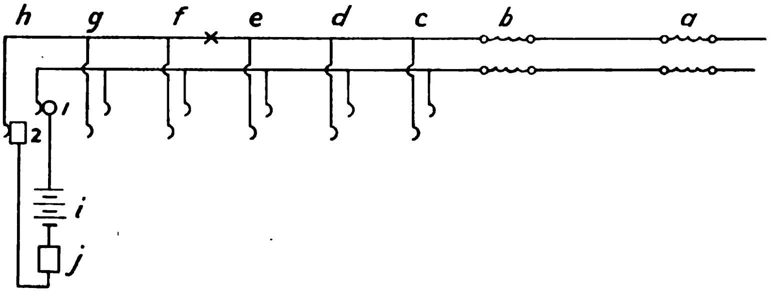


Fig. 269.

Trouble located between the first and last section of switchboard, is said to be in the multiple and is usually found at the point where the cable conductors are soldered to the jacks. It should be remembered that in the case of a bridging board, a separate test must be made on the answering jack wiring, and the answering jack wiring must be cut off when a test is made on the multiple. This is accomplished by unsoldering the wires at the intermediate distributing board.

On very rare occasions the cable conductors open in the cable. When this happens the defective pair is unsoldered from the jacks at the two sections between which the break is located and a spare pair, with which the cable is equipped, is substituted. As a parting remark, when a line is tested at the main rack, great care must be taken to test the heat coils for continuity before they are replaced. For should the open be located at this point, the line will test O. K. when taken up at the main rack, but will immediately show open when the heat coils are replaced. This combination will cause the wire chief a great deal of trouble before the defect is located.

The method employed for testing heat coils is to use two or three dry cells connected in series with a buzzer. The two terminals of the circuit are soldered to two clips, one shaped like the heat coil spring and the other like the ground spring of the arrester. They are also separated by the same distance as these springs. The heat coil to be tested is placed between these two clips, closing the circuit and sounding the buzzer if it is in proper condition. If the buzzer fails to sound, it shows that the heat coil is open.

As has been already stated, a *ground* is caused by one or both sides of the circuit coming into electrical contact with the earth. When a line is grounded on both sides, the effect is similar to a short circuit. The characteristic effect of a ground is to throw noise on the line due to the presence of the earth currents on the line. The wire chief, in testing, therefore, has to locate the point at which the noise originates. He is assisted by the relay and sounder, but the final adjustment must be made by the ear. The routine adopted in making the test is the same as that employed in testing opens.

The line is first taken up at the main rack, the testing circuit being inserted into the jack *d*, Fig. 268, thus cutting off the switchboard end. If the line be grounded outside, the relay *f*, Fig. 265, will be closed by the current from the battery *e*, flowing over the line to the grounded point, and returning through the ground *x* to the relay. But since the same condition will prevail on a normal circuit as on a grounded one, the only way to differentiate is to feel with the finger the pull on the relay armature. In the case of a normal circuit, the line is closed through the 1,000-ohm bell, and the current flow through the relay is determined by the E.M.F. of the battery divided by the resistance of the line and bell together. When the line is grounded, however, the return circuit is made through the earth, if the battery is connected to the grounded side of the line, and the bell is cut out. The resistance of the circuit carrying the testing battery is reduced by this amount, and the current flowing through the testing relay is proportionately greater, so that the pull on the testing relay armature is greater under these conditions, than is the case with a normal line. To ensure the testing battery being cut in on the grounded side of the line, the relative position of the testing plugs *a* and *a'*, Fig. 268, must be reversed. This point will be understood better by referring to Fig. 270, where 1 and 2 represent the two sides of a line with the telephone bell at *a*. The tip of the testing plug,

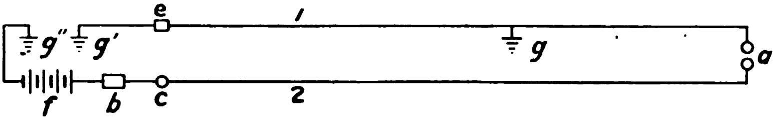


Fig. 270.

Fig. 265, is shown at *c*, and the shank of the plug at *e*, the relay at *b*, the battery at *f*, and the two grounds on the testing circuit at *g'* and *g''*. The trouble is located at *g*. With the conditions as shown in the figure, the battery is on the side of the line opposite to the ground, so that the testing battery must flow through the bell coils to reach *g*. The portion of the line between *g* and *e* is the only portion cut out, and the resistance cut out of the circuit thereby bears such a small proportion to the resistance of the whole line, that the current through *b* is not increased sufficiently to make any material difference in the pull of the relay armature. If now, the relative positions of *c* and *e* are changed, so that the testing battery is sent out on the No. 1 side of the line, the bell coils are cut out, and the pull on the relay armature increased sufficiently to be readily detected.

The above conditions hold good whether the ground is located within or without the exchange, for in the former case, the drop coil takes the place of the bell coil, and the circuit tests out the same way. Assuming that the trouble is located in the exchange, the same process is carried out as in the case of an open, with the exception that the defective portion of the line must be cut off in every case. The defective line being ordered up on the last section, it is opened at the main intermediate distributing board. If under these conditions the line clears, the trouble will be located between the main and intermediate distributing boards. If on the other hand the line still shows trouble, the wire chief knows that the defective point lies between the intermediate board and the last section of switchboard.

If the switchboard is of the series type, and the ground be on the spring side of the jack, the ground can be located by using a plug made of hard rubber, or an ordinary plug to which nothing is attached. Because plugging into the jack opens the line, so that by plugging on each section the defective portion of the line is cut off until the section on which the ground is located is passed. The ground will be located between the last section on which the trouble was cut off on plugging in, and the first section on which it was not. Since it is not practicable to unsolder the multiple jack wiring, some other device must be resorted to in the case of a bridging switchboard, or a series board, when the trouble is on the ring side of the jack.

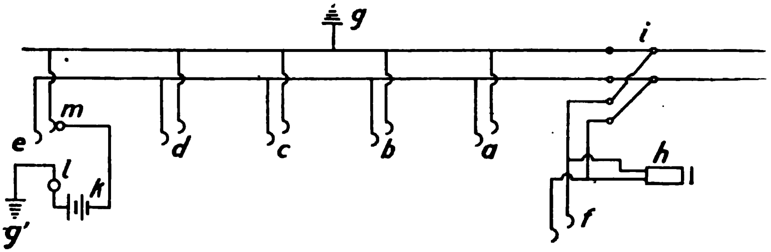


Fig. 271.

Such a device is shown in Fig. 271, and depends for its action on the ability of the ear to detect the diminution of the flow of current in a receiver, caused by the resistance of the switchboard wiring. It has proven to be very useful and saves a great deal of time that would otherwise be wasted in searching through the switchboard wiring. Here the multiple jacks are shown at *a*, *b*, *c*, *d*, and *e*; the trouble being located at *g*, between *b* and *c*. The answering jack is shown at *f* and the drop at *h*. At *k* is shown a battery of dry cells, one pole of which is wired to a receiver *l*, whose other terminal is grounded at *g'*; and the other pole is wired to the tip of a plug *m*. The intermediate distributing board is shown at *i*, and the answering jack wiring is thrown off at this point. The plug *m* is then inserted into the jack *e*, a circuit being made for the battery *k* through the ground *g*. As a result, a click is heard in the ear, directly the contact is made. The plug is then inserted at *d*. This time the resistance of the circuit is reduced by the amount of resistance in the wiring from *d* to *e*, which makes an appreciable effect in the distinctness of the click. At *c* the click is still louder and of equal intensity to what is experienced at *b*. At *a* it is again diminished. Should the ground be located on the opposite side of the line, it will be detected by the fact that the line will show open when the plug is inserted. Under these conditions, the tip strand of the cord is removed from *k* and the ring strand substituted. If the trouble be located in the answering jack wiring, it will disappear when the latter is disconnected.

The next class of troubles to be considered is the *short circuit*, in which both sides of the line come into electrical contact. The method of handling this trouble is identical with that described for grounds, with the exception that in making the receiver test, the battery and receiver are wired to the ring and tip of the testing plug.

The class of troubles known as *crosses*, necessitate the use of an auxiliary testing circuit, but in other respects they are handled just like the grounds and crosses. The auxiliary circuit made use of has already been shown in Fig. 265, where the plug *l* is wired to a reversing key *m*, one side of which is grounded. In testing for crosses, the two lines in trouble are taken up on the main distributing board by means of two testing circuits, one of which is shown in Fig. 267. The plug *a*, Fig. 265, is inserted into the jack *e*, Fig. 268, while the plug *l* of the auxiliary testing circuit, Fig. 265, is inserted into the corresponding jack on the other testing circuit similar to Fig. 268. The switchboard portions of both the lines in trouble are thus cut off.

The principle of locating a cross depends upon the fact that if two lines are connected together, a ground thrown on one line will ground the other also, and the location of the cross will be determined by the pull, on the relay armature, as in the case of a simple ground This will be illustrated by reference to Fig. 272. Here let 1, 2, 3, 4 be the conductors of two subscribers' circuits, each with the bell bridged across, and let conductors 2 and 3, be crossed at *x*. Let *a*, *b*, and *c* be the tip of the testing plug, the relay and grounded battery respectively; and *a'* be the plug of the auxiliary circuit. Let the former be connected to the No. 2 side of the line, and the latter to the No. 3 side of the line. It is plain that a path for the current from *c* is formed through the cross at *x*, back over conductor No. 3, to the auxiliary test plug, and thence to ground at *g'*. The resistance of the telephone bell and a portion of the line being cut out, the pull of the relay armature will be much stronger than normally. The relative positions of *a* and *a'* must be reversed in order to determine on which side the cross is located. In other respects, the location of a cross is determined in the same manner as a short circuit.

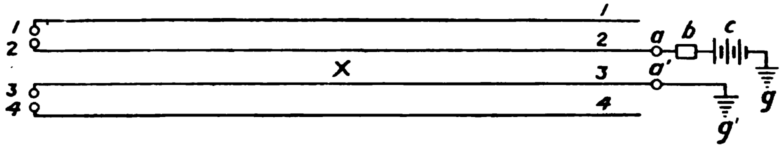


Fig. 272.

There remains to be discussed one more class of trouble, the *escape*. As has already been explained, the escape is a high resistance ground, and its presence is felt through the line becoming noisy, due to the presence of induced earth currents. With the magneto system, escapes were tested by means of the ear only, and when the trouble was located outside of the exchange, it was as it is to-day, turned over to the cable maintenance department. When an escape occurs in the switchboard wiring, it is usually due to the fact that dampness in the air has saturated the cables and wire. This is apt to occur in the damp warm days of summer, and along the seashore. It can be remedied only by thoroughly heating the atmosphere of the exchange, and by the application of chloride of lime around the cables and wiring. Switchboard cords are very apt to saturate from this cause and have to be changed very frequently.

CLEARING OF TROUBLE.

So far nothing has been said of the clearing of trouble that is located on the line outside of the exchange, as this work is attended to by a force of men different from that mentioned above. The outside force is divided into two groups. *Inspectors* who clear the station troubles, and *troublemen* who clear the troubles located on the lines. The inspectors also perform routine inspection of the telephones, and maintain them in good working order. It will be evident from an inspection of the telephone wiring, that all of the above-mentioned troubles may be located in this apparatus, and the wire chief often has nothing but his experience to guide him in determining whether the case requires the office of an inspector or troubleman. The trouble being located on the line, however, the wire chief sends out a troubleman, giving him the number of the cable in which the conductors are located, together with the numbers of the conductors and the location of the distributing point. If the line is made up wholly or in part of open wires, the pole numbers and wire numbers are also given. The troubleman is equipped with a pair of spurs and a lineman's test-box, which is nothing more than a portable magneto telephone wired as shown in Fig. 273, where 1 and 2 are binding posts to which the line is attached; *a*, a switch pivoted at 5, and playing over the points 3 and 4. At *d* is a receiver which is also used as a transmitter; at *b* is a buzzer and at *c*, a series generator. One

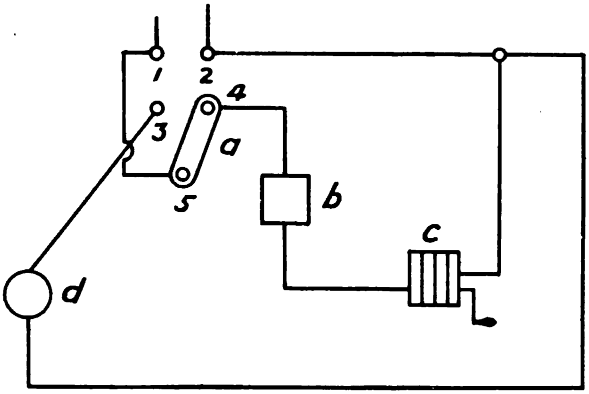


Fig. 273.

pole of the receiver is wired to the switch point 3, while the other pole is wired to the binding post 2. One terminal of the buzzer is wired to the switch point 4 and the other terminal to the generator. With the switch in the position shown, the test set is ready to receive or transmit a signal; while with the switch thrown to point 3, the buzzer and generator are cut out, and the receiver cut in for talking.

Equipped as described, the troubleman goes to the distributing point, cuts in on the given conductors by means of a flexible cord equipped with two clips for holding to the lugs in the cable box. Assuming the trouble to be an open, he rings, and if the trouble lies between himself and the exchange, he will raise the subscriber but not the operator. If on the other hand he is unable to raise the subscriber, but the operator answers, he knows that the trouble lies between himself and the subscriber. If the trouble lies between the distributing point and the exchange, the wire chief is called and a new pair of conductors is taken to carry the line. Should the trouble be located between the subscriber and the distributing point, this portion of the line is gone over very carefully and the fault remedied. It may be that through mechanical injury a portion of the distributing or drop wire has been broken. If so this must be spliced temporarily, so as to get the subscriber working as quickly as possible. If need be, the line will be permanently repaired at a later date.

These breaks are very apt to take place where the line passes through trees, as under the influence of high wind, the swaying of the branches is apt to break the wire. Where such conditions exist, or where from any one cause or another, the line is apt to be again thrown into trouble, a report of the fact should be made by the troubleman, so that the conditions may be permanently bettered. The largest percentage of line troubles will be found to be located in the contacts of the cable box.

The station trouble consists almost altogether of parts of the apparatus getting out of repair, and the work of the inspector is that of either repairing or replacing them. About 80% of the transmission troubles are found to be due to weak batteries. When Leclanché cells are used the inspector replenishes them himself. When Fuller batteries are used he directs the battery man to perform the work.

With the introduction of the *common battery system*, a more elaborate testing circuit was devised for the wire chief, and a voltmeter was introduced. The lines to the first and last sections of switchboard were also wired more elaborately. In considering the subject of testing trouble with the common battery system, it must be remembered that in this case the subscriber lines test normally open, which is not the case with the magneto system. Furthermore, battery being on the line continually, it can always be used

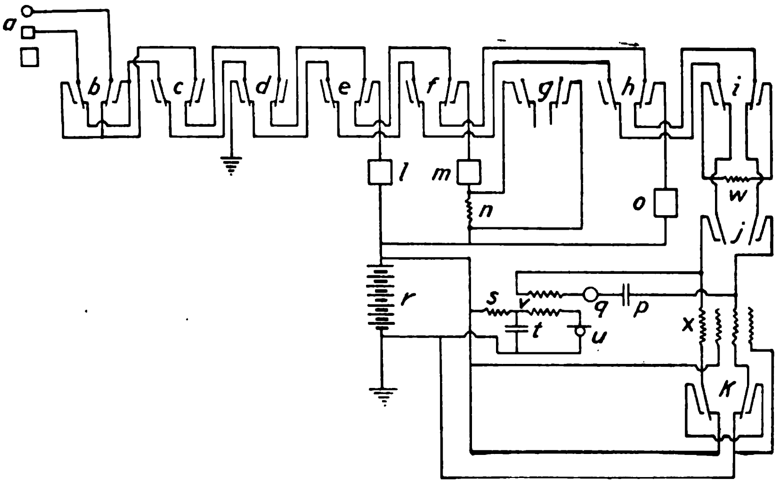


Fig. 274.

to test with. This feature makes it, in some respects, easier to locate trouble on the common battery system than on the magneto system. In Fig. 274 is shown the wiring of the wire chief's testing circuit used in connection with the common battery system. To a cord and plug *a* are wired ten keys, designated by the letters of the alphabet. The key *b* is called the reversing key, because, as will be seen, current coming from the battery *r* can be thrown either on the ring or tip of the plug. At *c* is the ringing key, the ringing generator leads being connected to the two outer points. At *d* is the grounding key for throwing ground on one side of the testing circuit. This side is always opposite to that on which the battery is connected. By means of the key *e*, the voltmeter *l* of special design, with the battery *r* in series, is thrown on one side of the line. At *f* is the ammeter key, by means of which the ammeter *m* with the battery *r* in series is thrown on one side of the line. For the safety of the ammeter, a resistance *n* of 100 ohms is connected in series with it. This may be short circuited by the key *g* if so desired. At *h* is a key for cutting in a telegraph relay *o*, the same as the one shown in the magneto testing circuit. To the armature of this relay is wired a sounder not shown in the diagram. At *i* is the holding key, which is thrown across the circuit, to hold a line, should the wire chief desire to talk on some other line for a moment. The testing key is at *j* and deserves

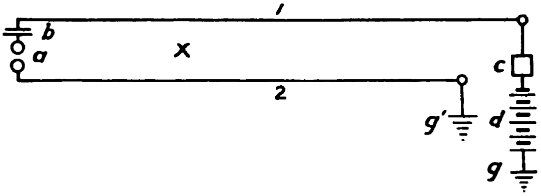


Fig. 275.

special mention. At *x* is a repeating coil wired as a retardation coil, battery coming through the inner points and swinging contacts of the key *k*. The receiver *q* of the wire chief's telephone circuit is bridged across the circuit with a 2 M.F. condenser *p*, and the secondary winding of the induction coil in series. The key *k* has its outer springs strapped together, so that by throwing it, the two halves of the repeating coil winding are strapped together and battery cut off. The above circuit gives a very elaborate means of testing, and is used as follows:

The line to be tested being taken up in one of the ways already described, the grounding key *d*, is thrown, thus grounding one side of the line. The voltmeter key is then thrown, so that this instrument with grounded battery in series is connected to the opposite side of the line. If the circuit is in normal condition, it will be open to direct battery at the subscriber bell, so that the needle of the voltmeter *l* will not be permanently deflected. The condenser in series with the bell, will however become charged. If the reversing key *b* be thrown, thereby changing the direction of the battery potential on the line, the condenser will be discharged, and then charged in the opposite direction, which action causes the voltmeter needle to make an excursion, depending in magnitude upon the capacity of the line, and to again return to zero. Should the line be open between the point where it is tested and the subscriber station, there will be no excursion of the needle when the voltmeter is thrown This excursion, therefore, is the indication of a normal condition of the line Should the line be short circuited, the condenser will be strapped out, and the circuit will be closed to direct current, so that under the proper conditions there will be a permanent deflection of the voltmeter needle, when that instrument is thrown on to the line.

This point will be understood better by reference to Fig. 275, where the testing circuit and the line to be tested are shown in outline. Let 1 and 2 be the two sides of the line to be tested; and let *c*, *d*, and *g* be the voltmeter, battery and ground respectively; while *g'* is the ground thrown on the opposite side of the line by the grounding key. Let the line be short-circuited at *x*, then under the conditions shown, current will flow from *d* through the voltmeter *c* to No. 1 side of the line, returning through the short circuit *x* to the No. 2 side of the line to the ground at *g'*. If the ground at *g'* is removed, which is equivalent to releasing the grounding key *d*, Fig. 274, the voltmeter circuit would be opened and the needle would return to zero. *Therefore, if when the voltmeter key and grounding key are both thrown, a deflection is obtained, and if the needle returns to zero when the grounding key is released, the line tested is shown to be short circuited.*

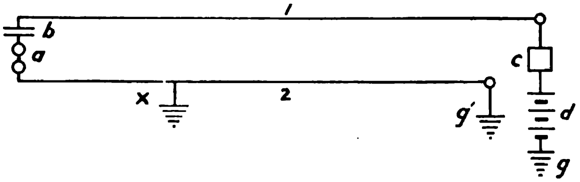


Fig. 276.

Suppose, now the line to be grounded, the conditions shown in Fig. 276 will obtain. Suppose that the line to be tested is grounded at *x*. the testing circuit being connected up as in the previous figure, the same letters of reference being used. With the conditions as shown the line will test normal, because the ground *x* being on the opposite side of the testing battery, the circuit will test open through the condenser *b*, and the ordinary swing of the needle will be obtained. Should, however, the ground *g'* be removed by releasing the grounding key *d*, Fig. 274, the line will still test normal, for the return circuit will be made through the ground at x to the ground at g. *Therefore, should a swing of the voltmeter be obtained when the grounding key is released, the line tested will prove to be grounded on the side opposite to that on which the voltmeter is connected.*

If the reversing key b, Fig. 274, is so adjusted that the voltmeter and battery are connected to the No. 2 side of the line, while the grounding key is connected to the No. 1 side of the line as shown in Fig 277, then a steady current would flow through the voltmeter out on the No. 2 side of the line, to ground at x and return, and the voltmeter would be permanently deflected. This current flow would be altogether independent of the presence of the ground g'. *Therefore, should the voltmeter needle be permanently deflected when the grounding key is released, the line tested will prove to be grounded on the same side as that on which the voltmeter is connected.* If the voltmeter used on the testing circuit is of the proper sensitiveness the insulation of the line can be measured. Referring to Fig. 275, it will be seen that any leakage current, either from the line to ground, or from one side of the line to the other, will flow through the voltmeter, and if the instrument be sensitive enough, the magnitude of the insulation resistance can be determined by means of the following considerations:

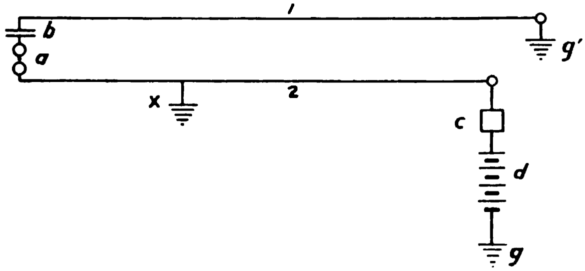


Fig. 277.

Let E denote the E.M.F. of the battery used for testing; e denote the reading on the voltmeter for any given leakage current; let R denote the insulation resistance, and r the resistance of the voltmeter.

In Fig 278, let *b* be the testing battery, *a* the voltmeter, and the lines 1, 2, 3, 4, etc., denote the leakage. The current flowing through the voltmeter is given by the expression

$$I = \frac{e}{r} \tag{1}$$

where I denotes the flow of current.

Again, the current flow is denoted by the following different expression

$$I = \frac{E}{R + r} \tag{2}$$

Placing the right-hand member of 1 equal to the right-hand member of 2, we get

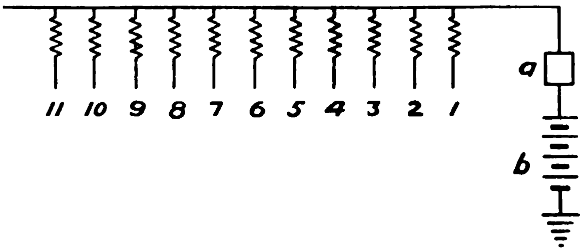


Fig. 278.

$$\frac{E}{R + r} = \frac{e}{r} \tag{3}$$

Clearing fractions $(R + r)\,e = Er \tag{4}$

or $Re + re = Er \tag{5}$

from which $Re = Er - re \tag{6}$

Simplifying $Re = (E - e)\,r \tag{7}$

Solving for R. $R = \frac{E - e}{e}\,r \tag{8}$

Equation 8 gives the insulation resistance of the line in terms of the voltage of the battery and the resistance of the voltmeter, so that the sensitiveness of the apparatus will increase with the potential of the battery used and the resistance of the voltmeter coil.

At first thought it might seem as if the sensitiveness could be increased without limit, by increasing the potential of the testing battery. The limit to which this voltage can be increased is governed by the fact that the higher the voltage used, the greater the strain upon the insulation. In the testing of cables, the usual practice is to test with 100 volts of chloride of silver battery, as this potential is considered to be high enough to give sufficient sensitiveness and not high enough to subject the insulation to undue strains. In connection, however, with such testing as the wire chief does, it is not essential to get as high a sensibility and for the sake of economy, the same battery is used for testing as is used for operating the station, so that the value E, in the above equations is given at 24 volts. It therefore becomes necessary to increase the other quantity as much as possible. The highest resistance of voltmeter winding used for this purpose is 40,000 ohms, so that the highest insulation resistance that can be read with this combination is given by the following expression: Let $E = 24$ and $r = 40{,}000$, and $e = 1$, the smallest reading on the voltmeter. Then $R = \frac{E - e}{e} r$ becomes $R = \frac{24 - 1}{1} 40{,}000 = 23 \times 40{,}000 = 920{,}000$ ohms, almost 1 megohm. Lines having an insulation resistance equal to this figure are in good condition, and unless this quantity decreases from day to day no attention need be paid to it The smallest insulation resistance that can be measured on this instrument is given by the following expression: Let $E = 24$ volts as before, $r = 40{,}000$, and $e = 23$, the maximum reading of the instrument next to a dead ground. Then $R = \frac{E - e}{e} r$ becomes $R = \frac{24 - 23}{23} 40{,}000 = 40{,}000 \div 23 =$ 1,740 ohms.

Lines having as low an insulation resistance as the above need attention immediately. Roughly speaking, when the insulation resistance falls below 40,000 ohms the line needs attention.

In speaking of the testing circuit, Fig. 274, an ammeter *m* controlled by a key *f* was referred to. This ammeter, or rather milliammeter, is used to measure lower resistance than 1,740 ohms, and is useful in locating crosses, short circuits, and dead grounds. The milliammeter used has a reading of 0 to 500 milliamperes or ½ ampere. The expression used to determine resistance by this instrument is derived from Ohm's law:

$$I = \frac{E}{R};\ R = \frac{E}{I} \qquad 9$$

where R is the resistance to be measured, E the potential of the testing battery, and I, the current density flowing through the ammeter. The highest resistance that can be measured with this combination is determined in the following manner: Let $E = 24$ volts and $I = .001$ or $\frac{1}{1000}$ ampere. Then equation 9 becomes $R = \frac{24}{.001} = 24{,}000$ ohms. Likewise the smallest resistance that can be measured is given by the following, assuming that $E = 24$ and $I = 500$ milliamperes or .5 ampere. $R = \frac{24}{.5} = 42$ ohms.

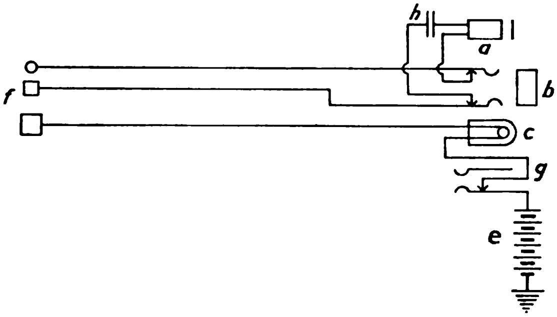


Fig. 279.

While high resistance can be measured with the ammeter, it is not as sensitive for the purpose as the voltmeter, so that the latter instrument is always used. For low resistances, the ammeter covers a field that cannot be reached by the voltmeter, hence its use. The method pursued by the wire chief in the use of these instruments is as follows: The voltmeter is first used, and if the resistance is so low that a full reading is obtained, the ammeter is then thrown on. A record is kept by the wire chief of the normal resistance of each line with the receiver at the subscriber station removed from the hook. This, of course, refers to the metallic resistance of the line and not to the insulation resistance. By this means when a short circuit or dead ground occurs on any one of these lines it can be determined by comparison.

The telegraph relay is used in the same manner as described for the magneto circuit, and therefore needs no special mention.

The battery key k is used when the wire chief is talking to a lineman with a test box, as under these conditions it is not necessary to throw battery on the line. In all other respects, the locating of trouble is performed in the same manner as that described for the magneto system. The lines to the main distributing board possess no new features, but the lines to the first and last sections of switchboard are characteristic and are shown in Fig. 279, where f denotes the plug at the switchboard, and b the jack on the wire chief's desk. To the points of the jack is connected the drop a with a condenser h in series. The drop is provided for the convenience of the line men in calling up. Wired to the shank of the plug f is a lamp c, the battery lead being run through a key g. When the plug is introduced into the subscriber jack, the battery e is grounded through the cut-off relay, and current, therefore, flows through the lamp, thus indicating to the wire chief by its illumination that the line has been taken up by the operator. By depressing the key g this lamp circuit is opened, and current removed from the cut-off relay of the line being tested, so that this relay being released, direct current is thrown on the line. Under these conditions when the wire chief throws the listening key on his testing circuit, the line lamp becomes illuminated. This affords the wire chief a means of quickly testing the answering-jack wiring.

While the use of the voltmeter affords a great help to the wire chief in detecting and locating trouble, he must possess a trained ear, and be thoroughly familiar with the nature of the construction of the line both inside and outside of his exchange. He must also possess executive ability in a high degree to successfully deal with the large volume of business that is transacted at his desk in the course of the day.

CABLE MAINTENANCE.

The clearing of trouble in cables is a much more elaborate piece of work than that of clearing trouble in open-wire lines, bridle wires, or drop wires, since it always necessitates the opening of old splices and the making of new ones. The work of locating trouble, too, necessitates the use of delicate scientific instruments and more or less complicated mathematical formulae. This work, therefore, cannot very well be handled by the force under the wire chief, and in the larger companies is performed by the construction department, a sub-department being provided for this purpose. The force of men employed in this work consists of a gang of cable splicers and a gang of galvanometer men with their assistants. The size of these two gangs depends on the size of the cable plant, and the volume of business to be done. Large companies that have a great number of underground cables, find that they are getting out of order all the time, so that these two forces are continually employed in locating and clearing cable trouble.

All reports of cable trouble come to the construction department from the wire chief, who, by the methods already described, locates the trouble in the cable. The work of clearing the trouble is divided into two distinct heads: First, *locating trouble.* second, *clearing trouble.* The work of locating trouble is performed by the galvanometer man, and for this purpose he is equipped with a galvanometer of one of the portable types, a battery of 100 chloride of silver cells, a battery reversing switch, and a capacity switch. A standard megohm coil should also be provided. Some form of lamp stand and scale will also be necessary.

Lead cables are thrown into trouble from three causes: *Mechanical injury*, *deterioration of the lead sheath due to electrolysis*, and the *burning of the conductors and sheath by accidental contact* with high foreign potentials, such as lightning, trolley current and the like. The fact that a cable is deteriorating is made known by the increasing number of troubles that are found to be located in it, and when such a condition prevails the galvanometer man is sent out to locate the trouble. As a usual thing the galvanometer man makes his test from the exchange, and to this end sets his instruments at this point. Except in the case of mechanical injury, or injury due to lightning, the trouble from which cables are most likely to suffer is grounding. In the case of mechanical injury, or lightning, grounds, short circuits, crosses, and opens are apt to be encountered. The nature of the trouble with which a cable is afflicted is usually reported by the wire chief, but the galvanometer man, while he uses the wire chief's report as a guide, must nevertheless make a thorough determination as to whether or not any other trouble exists.

Thompson Galvanometer. In Fig. 280 is shown one of the best adapted forms of the Thompson galvanometer for cable-testing work. It consists of 4 coils, two of which are shown at a and a' mounted on two ebonite pillars b and b', which in turn are supported on an ebonite base c. This base is equipped with three leveling screws d, d', and d''. The terminals of the coils are brought out to binding posts placed on the ebonite base, four of which are shown at e, e', e'', e'''. The system is suspended by an unspun silk thread, which is fastened to the milled-head screw f. The upper magnet of the system having the mirror attached is shown at g, while the lower one is shown at h. The coils are enclosed in a cylindrical glass case i, upon the metal top of which is mounted the vertical rod j carrying the control magnet k. The bottom of the rod is equipped with a worm wheel into which meshes a screw l with a milled head m. The control magnet makes a binding fit over the rod, and coarse adjustment can be made with the hand. Fine adjustment is made with the screw and worm wheel. The glass case fits air-tight, so as to exclude the dust.

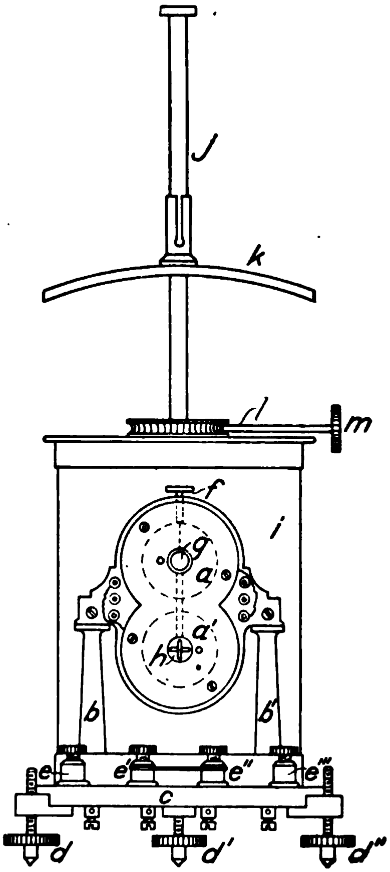


Fig. 280.

In Fig. 281 is shown the plan of wiring the coils and method of bringing the terminals to the binding posts. By following the direction of the arrows, it will be seen that by properly connecting together the binding posts 2, 3, 4, 5, 6, and 7, the coils can be connected in series or multiple as desired, and that any one of the coils can be cut out at will. A leveling glass, shown at *a*, is provided by means of which the instrument can be accurately adjusted in this respect.

D'Arsonville Galvanometer. While this type of instrument gives very good results, and is the best form of the Thompson type for portable work, it is not as good as the D'Arsonville galvanometer, a very excellent form of which is shown in Fig. 282. This instrument is as sensitive as the Thompson, but is much more easily set up and adjusted, and is absolutely unaffected by fluctuations in the earth's field. The permanent magnet is laminated, thus ensuring a high degree of magnetic saturation in the iron. The system is suspended top and bottom in the metal tube, which can readily be placed in position and secured with a screw. By means of a small nut at the bottom of the tube, the system can be held rigidly, when the tube is being carried about, thus preventing mechanical injury.

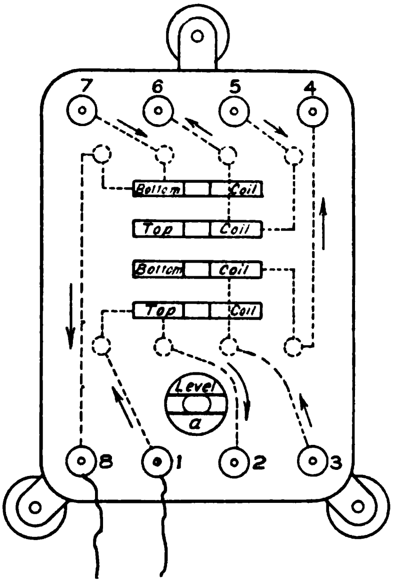


Fig. 281.

Battery reversing keys are made up in several forms, one of the most approved being that shown in Fig. 283. Here six binding posts E, E′, E″, D, F, and F′, are mounted on ebonite pillars to ensure good insulation. These columns are mounted on an ebonite base. To the binding posts E′ and E″ are attached two springs which carry at their opposite ends two ebonite buttons A and C. Each one of the binding posts F and F′ is equipped with a short strap at the end of which is a set screw. The ends of these two screws are platinum-pointed, and touch two platinum projections on the springs when the latter are in the normal position. The two binding posts E and D are connected by two copper rods to two posts H and H′ respectively, each mounted on an ebonite post. Two keys G and G′ are mounted on ebonite pillars, by means of which the springs are depressed, so that they break contact with F and F′ and make it with H and H′. Each one of these keys can be operated independently of the other. Whenever it is desired to depress either spring momentarily, the finger is pressed on either one of the buttons A or C. The method of connecting up this switch will be shown a little later.

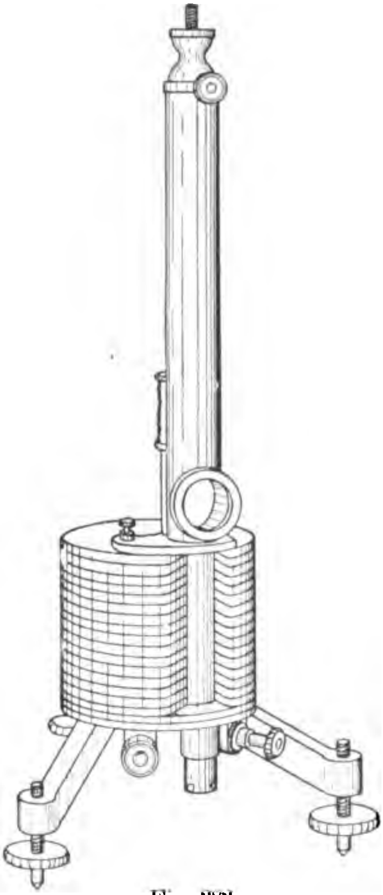


Fig. 282.

Capacity Key. The most approved type of capacity key is shown in Fig. 284, where mounted on an ebonite base is an ebonite pillar bearing a binding post *a*. To this post is attached a spring *b*, carrying at the other end an ebonite button *c*. Two other binding posts *d* and *d′* each mounted on an ebonite column, are provided. Each binding post is equipped with a stout copper strap, the one attached to *d*, bending up and over the spring *b*; while the one attached to *d′* bends down and under *b*. Each strap is equipped at the end with a set screw, whose end is platinum-pointed. When the spring is in the upper position it makes contact with the upper set screw, and when it is in the lower position it makes contact with the bottom set screw, breaking its contact with the top one. Two keys *e* and *e′*, each equipped with an ebonite button, are so constructed as to catch the spring *b* when it is depressed, and hold it firmly. When, after the spring *b* has been depressed, the key marked *discharge* is tripped, it flies upward until it strikes against the upper set screw. When, however, the key marked *insulate* is depressed, the spring *b* flies upward until it strikes against the tooth of the discharge key, which holds it in a mid position insulated from both the upper and lower set screws. The method of connecting up will be described later. The standard megohm resistance used to get a constant is one of the many forms gotten out for this purpose, as is the standard condenser.

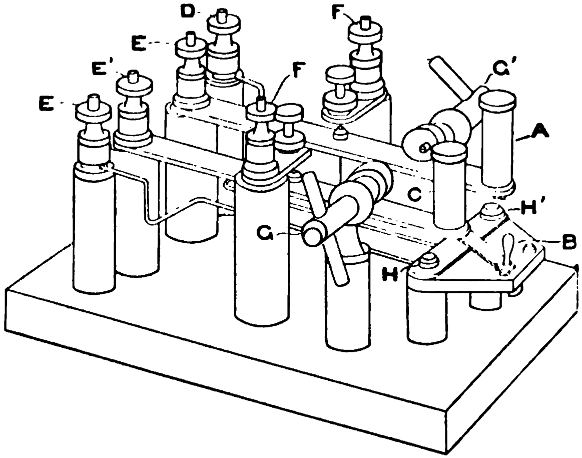


Fig. 283.

The method of wiring up the galvanometer, battery key, battery, and standard resistance to get a constant is shown in Fig. 285. Here *a* denotes the battery, *m* the battery reversing key, *b* a tapper key to short circuit the galvanometer, *d* the galvanometer, *c* the shunt, and *f* the standard megohm resistance. If the spring 2 is in its normal position, and spring 3 depressed, the current flowing from *a* will pass from contact 1 to spring 2 and thence through the galvanometer and shunt, when *b* is depressed, to the spring 3, from this point, to the contact *e*, through the megohm *f*, returning to the battery. If spring 2 is depressed and 3 normal, the direction of current flow through the galvanometer will be reversed.

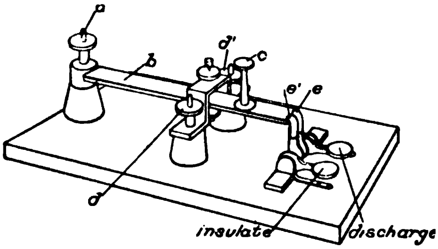


Fig. 284.

When a constant has been obtained, the standard megohm is reversed and the negative pole of the battery connected to the wire to be tested, the positive pole of the battery being grounded as shown in Fig. 286, where *n* represents the joint between the cable conductor and the test wire, the insulation on the conductor being shown at *p*, and the sheath of the cable at *o*. The terminal *e* is grounded. By means of the key *m*, either pole of the battery can be connected to the line and double readings taken. The magnitude of the deflections should be the same in both cases.

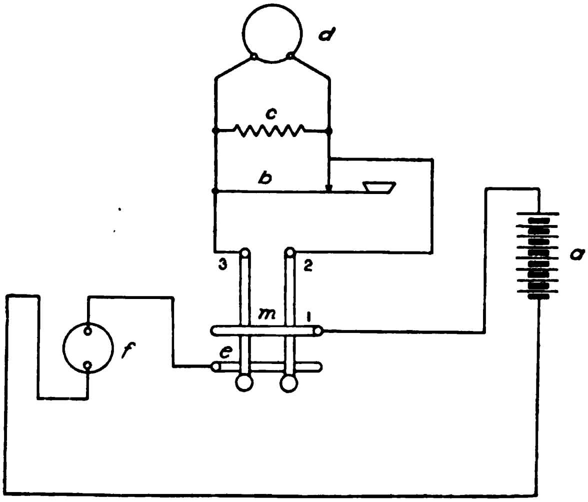


Fig. 285.

Measurement of Capacity. There are many methods adopted for measuring capacity, but the one oftenest employed by the galvanometer man is that of proportional deflections, and consists of charging the cable at a given potential, and noting the magnitude of the deflection at discharge, then comparing it with that obtained by discharging a condenser of known capacity that has previously been charged. The method of connecting up for this purpose is shown in Fig. 287, in which the standard megohm is replaced by a standard condenser *c* and the capacity key *k* is introduced. This key *k* is depressed, causing current from the battery to charge the condenser. The key *k* is then released, flies to its upper position and discharges the condenser through the galvanometer. When a constant deflection has been obtained the condenser is removed, and one terminal is connected to the conductor to be tested, and the other to ground, as shown in Fig. 288, where the contact *e* of the battery switch and one terminal of the battery are connected to the conductor at *c*, the insulation being shown at *a* and the sheath at *b*. The spring of the capacity key is grounded. With the key *k* in its lowest position the cable

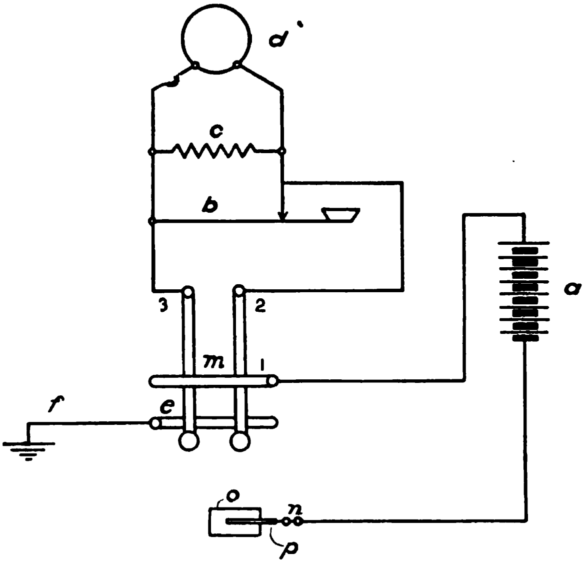


Fig. 286.

is charged. But when it is allowed to fly up, the battery is cut off and the cable discharged through the galvanometer.

Murray and Varley Loop Tests. The galvanometer man uses these two tests, to determine the insulation resistance and capacity of each conductor of the cable. The defective conductors are thus picked out and the next piece of work to perform is to locate the trouble found. There are two methods employed of doing this, each one having its peculiar advantages; and both having in common the advantage of simplicity. They are known as the *Murray Loop Test* and the *Varley Loop Test*. With both of these tests the Wheatstone bridge method is employed. The scheme of connection for the former is shown in Fig. 289. One terminal of the battery is grounded, and the other one is connected to the junction of *b* and *d*, or what is the same thing, between the rheostat and one arm of the bridge. The other arm of the bridge is plugged up as shown. Let *f* be the location of the ground located on conductor No. 1 and let conductor No. 2 be any other good conductor in the same cable, and suppose that their ends are joined

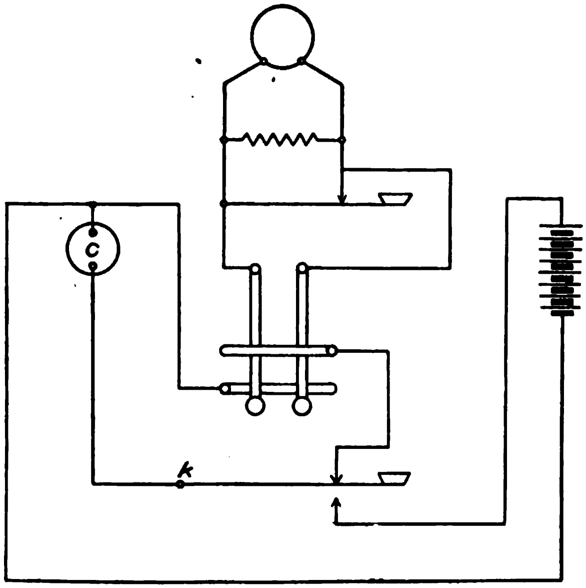


Fig. 287.

at *p*. The resistances at *b* and *d* are adjusted until a balance is reached and no current flows through the galvanometer. Denoting by *x*, the resistance of the conductor from C to the fault, and by *y*, that from E to the fault, we have

$$b \times y = d \times x \qquad \mathbf{10}$$

Denote by L the resistance of the whole loop, and we have

$$x + y = \mathrm{L} \qquad \mathbf{11}$$

$$y = \mathrm{L} - x \qquad \mathbf{12}$$

Substituting for *y* in equation 10 its value found from equation 12, we get

$$b\,(\mathrm{L} - x) = d \times x$$

$$x = \mathrm{L}\frac{b}{b + d} \qquad \mathbf{13}$$

which gives the resistance of the conductor from the exchange to the fault in terms of the two known resistances of the bridge, and that of the whole loop.

Knowing the gauge of the conductor the location of the fault can be determined from the resistance. To get the loop condition,

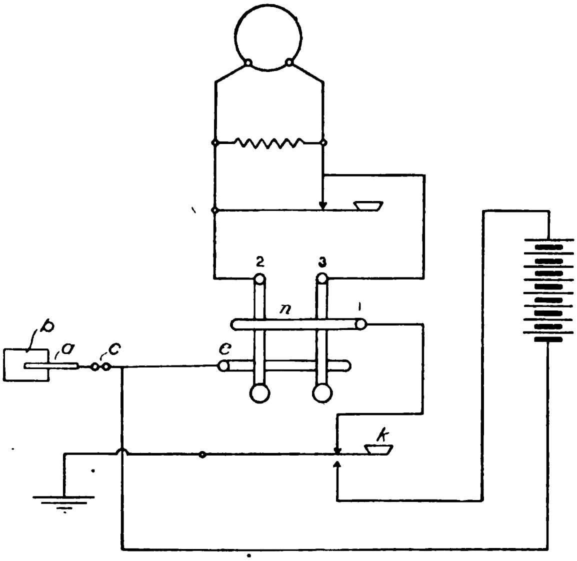


Fig 288.

all that is necessary is for the galvanometer man to send his assistant out to the cable box, at which point the defective conductor and a good one selected at random are joined. If more than one conductor be found defective, a test is made on each one, or on a sufficient number to determine that they are all defective at the same point.

In Fig. 290 is shown the scheme of wiring for the *Varley Loop Test.* Here B C and A B are the two bridge arms and A E is the adjustable resistance. The defective conductor is shown at No. 2 and the good one at No. 1 They are joined at *p*. The fault is at *f*. The resistance *d* is adjusted until balance is established, when we have

$$a\,(d + x) = b\,y \qquad \textbf{14}$$

where the symbols denote the same quantities as in the previous case Letting as before the total resistance of the loop be denoted by L, we have

$$x + y = \mathrm{L}$$

$$y = \mathrm{L} - x$$

Substituting $$a\,(d + x) = b\,(\mathrm{L} - x) \qquad \mathbf{15}$$

$$x = \frac{b\,\mathrm{L} - ad}{b + a} \qquad \mathbf{16}$$

If $$b = a \text{ then } x = \frac{\mathrm{L} - d}{2} \qquad \mathbf{17}$$

which gives the resistance to the fault in terms of the total resistance of the loop and the adjustable resistance.

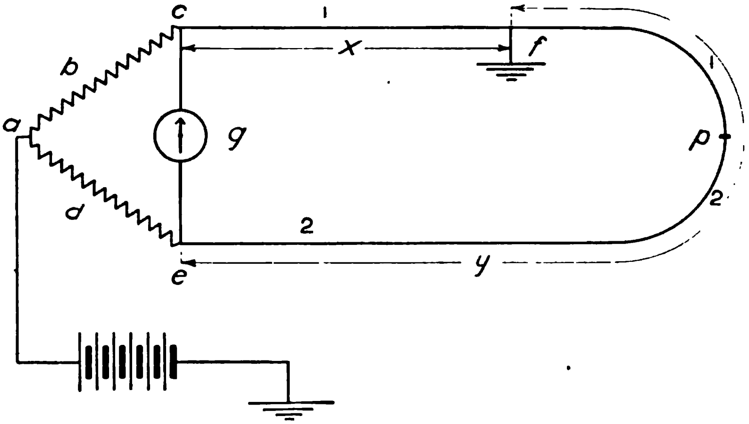


Fig. 289.

Cable faults are usually located in the splices, and are due to more or less careless work on the part of the cable splicer, in either not properly making the joints, or not properly placing the insulating sheeving, or not properly boiling out the splice after it has been made. Again, when the joint in the cable sheath has not been properly wiped, moisture is apt to leak in to the conductors, thus causing grounds. When the trouble has been located in the splice, the cable man is sent out to open it, examine its condition, properly re-make it and wipe it over again, after which it is again tested out to make sure that the trouble has been cleared. When the trouble is located in the cable between splices it is usually due to mechanical injury or to the fact that the cable has not been properly constructed. When, however, this condition obtains, the only thing to do is to replace the defective section, and this work is performed in the following manner:

Let *a* and *b* in Fig. 291 represent two manholes, and let 1, 1, 2, 2, 3, 3, etc., represent the conductors of a cable that has become defective at the point *x* between the two manholes. A new cable *c* is run in a spare duct between the two manholes, the lead sleeve on the old cable is removed in the manhole *a*, and the conductors of the new cable are joined to those of the old one at random. This having been done the lead sleeve is removed from the old cable and the conductors of the new cable are spliced to those of the old in the following manner:

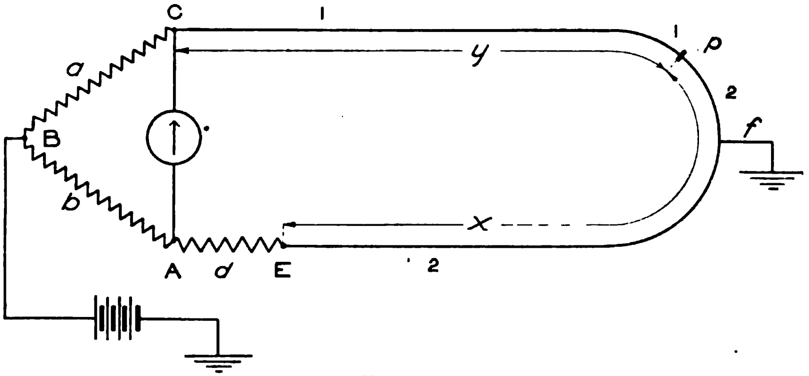


Fig. 290.

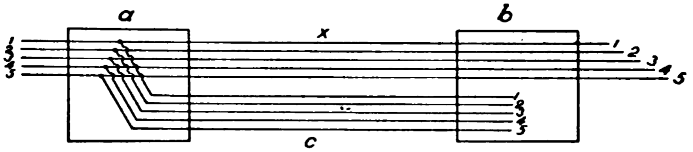


Fig. 291.

In Fig. 292 let 1, 2, 3, etc., represent the conductors as before, only three conductors being shown for simplicity. A telegraph relay *d* has one terminal connected through a battery *c* to one of the conductors selected at random as No. 1. The other terminal of the relay is grounded at *g*. To the local of the relay is connected the battery *d'* and the buzzer *f*. The lineman is equipped with a pair of shears *e*, which he always uses to skin off the insulation and to cut the wire. To these shears is attached a wire grounded at *g* With these shears he cuts through the insulation of all the conductors so as to touch the wire, and when the conductor to which No. 1 has been joined is reached, a circuit will be found through the shears and wire to ground, causing current to flow through the relay *d* and the buzzer *f* to ground The proper conductor having been thus located, it is cut, and the end of the portion from *b* on is spliced to No. 1 conductor in the new cable, while the portion running between *a* and *b* is left open. The circuit is thus made over the conductor in the new cable between the two manholes. The relay is then connected to another conductor in the new cable selected at random, and the conductor to which it has been attached, found as in the previous manner, and a joint made. This process is continued until all the conductors in the new cable have been joined to those in the old.

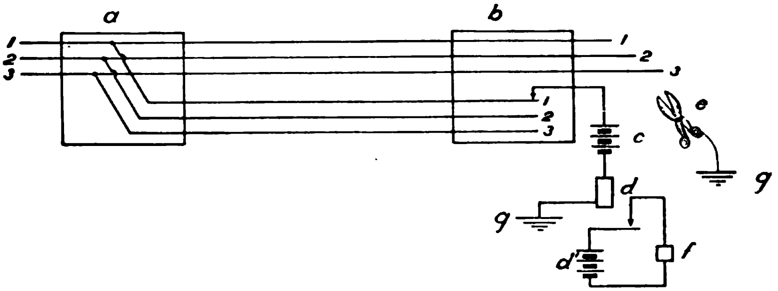


Fig. 292.

The condition at this stage is that shown in Fig. 293, where the conductors of the new cable are shown connected to those in the old cable at *c*, *d*, and *e*, in manhole *b*, while the conductors in the old cable are shown dead between the two manholes. Care must be taken not to short circuit or cross the free ends of these conductors in manhole *b*, as they are still connected to working wires. The lineman then goes to manhole *a* and cuts off the old conductors running between the two manholes, after which the new splices at *a* and *b* are boiled out and the joints wiped. The length of old cable between the two manholes is then pulled out and the work is completed.

THE PUPIN SYSTEM OF LOADED CIRCUITS.

The subject of increasing indefinitely the *long-distance limit of transmission*, is one which has interested telephone engineers ever since the beginning of the art. With the best possible construction, and the most improved apparatus, the limit of transmission over open wires is about 1,200 miles. When cables are used to make up portions of the line, this figure is materially reduced; the amount of reduction depending upon the percentage of cable with which the line is made up. This loss of transmission current is due to three factors, disregarding the leakage through the insulation resistance; and they are: *Resistance* of the line, *Capacity* of the line, and *Self induction* of the line.

The *resistance* factor can be reduced by increasing the size of the conductor; but this increase is limited, as has already been shown, by practical line construction considerations. The *capacity* factor cannot be affected, as in the best construction, it is already reduced as low as possible. The one remaining factor, that of *self induction*, seems to be the only one that can be looked to for aid in increasing the limit of transmission. This point was grasped by the pioneer writers in this field, and during the World's Fair in Chicago, Ill., the English scientist, Sylvanus P. Thompson, advocated the construction of a cable that should have electromagneto or retardation coils placed at intervals throughout its length, so that by increasing the self induction, the effect of the static capacity might be overcome and the limit of transmission thereby increased.

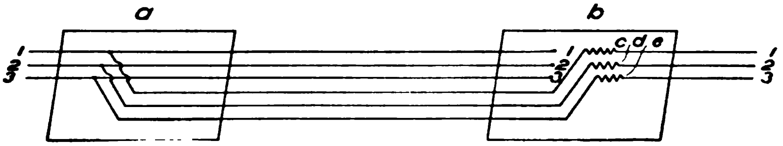


Fig. 293.

This scheme was subsequently tried several times, but so far from meeting with success, it was found that the transmission was not as good under these conditions, as with the circuit in normal condition. It was found that the presence of the magnetic coils on the line produced electric "echoes," which made the transmission very indistinct. The experiment showed that while increasing the self induction of a line uniformly throughout its length increased the distance over which transmission could be carried on, the presence of increased self induction at points along the line had the opposite effect. At this point the matter was allowed to rest, until Professor M. I. Pupin discovered in a very ingenious manner, the proper intervals at which the points of high self induction must be placed, in order that the effect would be the same as if the increased self induction were distributed uniformly throughout the length of the line. His method of reasoning was as follows:

To start with, the electrical energy in the talking current is transmitted from one end of the line to the other in wave motion. The amplitude and wave length depend upon two factors: *First*, the intensity and law of variation of the impressed E.M.F. at the transmitting end, and *Second*, the nature of the reactions of the circuit. The intensity and variation of the impressed E.M.F. at the transmitting end, will follow exactly the intensity and law of variation of the exciting force, which in the case under discussion is the energy of the sound waves. This quantity being easy of determination, nothing further may be said on the subject. The quantities to be considered are the reactions which take place in the circuit. It will be of material assistance to the proper understanding of the subject, if the analogous case of wave transmission over a cord, be considered first.

Suppose that in Fig. 294, one end *a* of the string *a b* be agitated backward and forward in the direction of the arrows by a simple harmonic motion. A wave of decreasing amplitude will be transmitted along the string from the point *a* towards the point *b*. That the amplitude decreases is shown by the fact that the ordinate 1-2 is greater than 3-4, which in turn is greater than 5-6, etc. The wave motion dies out before *b* is reached, so that no energy is felt at this point. Let us consider now the reaction that takes place in the string.

First, there is the *inertia reaction*, which is due to the kinetic energy stored up in the mass of the string.

Second, there is the *elasticity reaction*, due to the tension existing between the particles of the string when distorted.

Third, there is the *frictional reaction*, due to the production of heat.

Of these three reactions, the first and second are useful in propagating the wave motion through the length of the cord. The inertia of the cord acts like the inertia of the fly-wheel of an engine to absorb the energy given out by the piston rod, and give it out again to the machinery. The elasticity reaction being due to increased tension between the particles of the cord, tends to make it return to its original position.

The method of procedure is somewhat as follows: The end of the string *a* having been displaced to the right by the disturbing force, the inertia of the cord tends to transmit this motion to the remaining portion, and in so doing transforms itself into elastic energy or tension between the particles. When this tension has become equal to the energy of inertia, its reaction brings the string to rest, and causes it to move back to its original position. When the original position has been reached, this elastic energy has been retransformed into energy of inertia which carries the string past the original position to some point on the opposite side. As the string passes the original position, its energy of inertia is again transformed into elastic energy, till, when this transformation is completed, the cord again comes to rest. The elastic energy again causes the string to return to its normal position, and when this point is reached, the inertia again carries it to the other side. The frictional reaction tends to produce heat only, and is, therefore, useless in propagating the wave motion along the cord. Now, this motion will continue to be propagated along the cord until the successive losses due to the frictional reaction have become so great as to absorb all the energy, whereupon the string comes to rest.

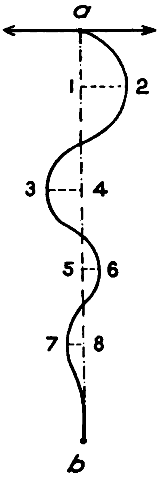


Fig. 294.

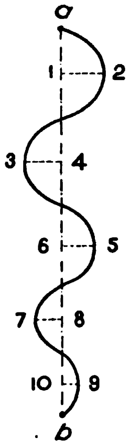


Fig. 295.

From these conditions it will be apparent that there are three methods by which the distance over which the wave motion can be propagated, may be increased:

First, by the reduction of the frictional reaction.
Second, by increasing the elastic reaction.
Third, by increasing the inertia reaction.

It is a well known principle of Mechanics that, all motion is attended by friction; so that while, with properly designed mechanism friction may be reduced materially, it can never be eliminated. Supposing that in the case of the cord just considered, the friction to be reduced as far as possible, the next thing to do is to consider the effects of increasing the inertia reaction and the elastic reaction. If the inertia of the string be increased by making it of heavier material, the inertia reaction will be increased correspondingly, and the ratio of the frictional reaction to the inertia reaction will be reduced so that the wave motion will be transmitted to a greater distance before the useful energy is absorbed, as shown in Fig. 295, and if the inertia is sufficiently increased some energy may be transmitted to *b*.

Again, should the elastic reaction be increased, by increasing the tension of the string, the distance over which the wave motion can be propagated will also be increased, as shown in Fig. 296. In this case, however, it will be noticed that the wave length is increased. So far the method of increasing the inertia considered has been by increasing the mass of the string uniformly throughout its entire length. The next method of increasing the inertia of the cord is by attaching weights to the string at intervals. If the intervals at which these weights are attached be properly selected, the result will be that the distance over which the wave motion is propagated will be equal to that of a cord of uniform mass, whose inertia is the same as that of the loaded cord. This point is illustrated in Fig. 297, where 1, 2, 3, 4, etc., represent the weights attached to the cord. It being assumed that the distance between the weights, *a–1*, *1–2*, *2–3*, etc., is the proper one, the mass of the cord plus the weights must be the same as that of the uniform cord shown in Fig. 295 in order to have the conditions of wave transmission the same in both cases.

It can be shown readily by experiment, that even if the mass be retained constant, and the weights be not placed at the proper intervals, the resultant wave transmission, so far from being improved by their presence, will be decreased, as shown in Fig. 298, where 1 and 2 represent two weights whose combined mass is equal to that of the weights shown in Fig. 297.

It will be seen then, that as far as the capacity for transmitting wave motion is concerned, a loaded string can be made equal to a uniform unloaded string, if sufficient mass be added to the former, to make the two strings equal in this respect, provided this added mass is subdivided and each portion placed at the proper interval along the string.

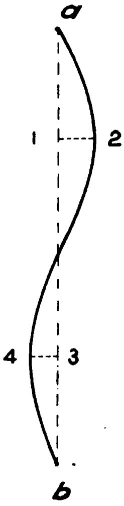


Fig. 296.

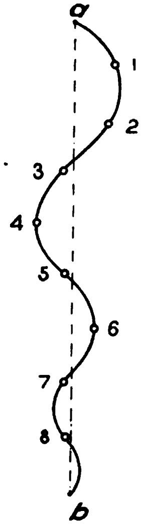


Fig. 297.

We are now prepared to consider the analogy existing between the case of wave motion being transmitted over a string, and electrical wave motion being transmitted over wire. When an alternating current is transmitted over a circuit, three reactions take place. First, *inductance reaction*, called ordinarily the counter E.M.F. of self induction, and which corresponds to the inertia reaction. Second, *capacity reaction*, which corresponds to the elastic reaction. Third, *resistance reaction*, which corresponds to the frictional reaction. Denote the inductance reaction by R_l; the capacity reaction, by R_c; and the resistance reaction, by R_r. Reaction as used in this discussion is defined as that quantity which, multiplied by the current flow, gives the rate at which energy is given out. Denoting therefore by I, the current flow, we have the following equations:

$R_l\ I =$ Energy expended in overcoming the inductance reaction.
$R_c\ I =$ Energy expended in overcoming the capacity reaction.
$R_r\ I =$ Energy expended in overcoming the resistance reaction.

Denoting the total energy delivered to the circuit by E_c we have $E_c = R_l\ I + R_c\ I + R_r\ I$, which is a statement in mathematical form of the law that action and reaction are equal. The first two reactions are called *conservative reactions* and are useful in transmitting energy over the circuit. The last is used up in *generating heat* only, and represents lost energy. The first two correspond to the inertia and elastic reactions in the case of the cord; and the last to the resistance reaction. The first, or inductance, reaction represents the energy utilized in producing a magnetic field around the wire. This magnetic field is capable of returning its energy back to circuit in the form of current. The capacity reaction represents the energy utilized in establishing an electrical stress between the conductor and its surrounding medium. This electrical stress is capable of returning its energy to the circuit in the form of current flow.

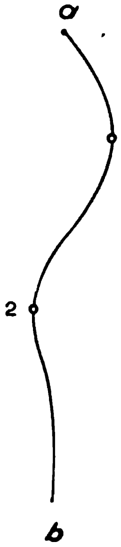


Fig. 298.

From mathematical considerations of the propagation of electrical energy along circuits, we have the following:

$R_l = a L$ where a is a constant and L the coefficient of self induction of the circuit. From the expression, it is apparent that the *inductance reaction* varies directly with the self induction of the circuit, so that the greater the self induction the greater will be its reaction.

Again we have

$$R_c = b \frac{1}{c}.$$

where b is another constant, and $\frac{1}{c}$ the reciprocal of the capacity of the line. From this expression it will be seen that the capacity reaction varies inversely with the capacity of the circuit; so that, the greater the capacity the less will be its reaction.

Again,

$R_r = R I^2$, where R denotes the resistance of the circuit and I the strength of current flow, this latter expression being well known.

From the above considerations it is evident that there are three ways of increasing the transmission limit: First, by increasing the self induction. Second, by decreasing the capacity. Third, by decreasing the resistance. The limit to which the resistance of the circuit can be decreased has already been discussed under Line Construction, so that this discussion will be limited to what can be done with the other two. With the use of the present paper insulated cables and open wire line construction, the capacity has been reduced to a point beyond which there does not seem to be any chance of progressing. Therefore, the only reaction that can be improved is the inductance reaction. As stated above, this point had already been recognized, but all attempts to make use of it led to failure, due to the fact that the points of increased self induction were not properly selected. These results were similar to those obtained when the vibrating cord was improperly loaded, as shown in Fig. 298. Professor Pupin's discovery consists in determining by mathematical considerations the proper intervals at which the points of increased self induction should be located. This interval varies with the capacity of the line, and for open wire lines has been established at 2½ miles, while for cables the interval is about 1,000 feet.

The scheme adopted is to cut into the line at the intervals mentioned, a retardation coil, thus producing a point of high self induction. These coils, called *loading coils*, are encased in iron boxes, made perfectly water tight, and so constructed as to be mounted on the pole. For cable work, they are placed in manholes, the case being so constructed as to be capable of being mounted on the side of the manhole.

For cable work, the loading coil has proved very successful; but in connection with open-wire lines, there has been experienced considerable trouble due to lightning. This difficulty will no doubt be overcome. Transmission is increased by the use of the load coil about 25 per cent.

PRIVATE BRANCH EXCHANGES.

Certain classes of subscribers, such as hotels, factories, and corporations located in the large modern office building, often require an extension of telephone service beyond that given under ordinary conditions. This arises from the fact that the number of calls per day for this class of subscriber is very high, and because a local service is required in addition. For example take the case of an insurance company occupying many rooms in an office building, and being subdivided into many departments, say ten. The head of each department requiring telephonic communication in his own office, it will be necessary, unless some other plan be devised, to place in each office at least one telephone connected to a direct wire to the telephone exchange. This arrangement would call for ten direct lines. Now the necessity for these ten lines arises from the fact that a telephone must be placed in each office, and not because this number is required to handle the business. It follows, therefore, that each line will be operated far below its normal capacity of calls.

To illustrate the above, suppose the total number of calls sent and received by the company per day to be 100. Assuming that the business is equally divided among the various offices, the total number of calls handled by each line would be ten, which does not approach the capacity of a telephone circuit.

Again, in addition to the calls to and from other companies, there would often be occasion for one department to hold communication with another, which under the existing conditions could be done by establishing the connections through the exchange in the regular manner. This means that for these inter-department communications, lines to and from the exchange must be maintained, whereas short lines extending only between the various departments are all that is required.

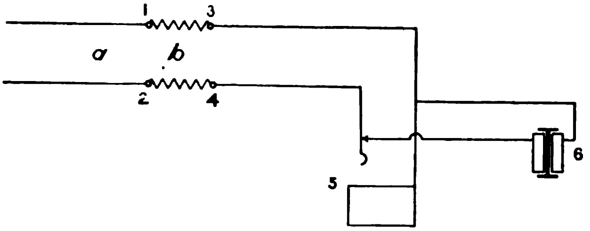


Fig. 299.

To handle this class of business on a more economical basis the *private branch exchange* was devised. The private branch exchange is nothing more than a switchboard placed in some convenient locality within the offices of the subscribing company. To this switchboard are run from the exchange a sufficient number of lines to handle the total number of calls for outside points. From this switchboard also extend lines to each one of the telephones placed in the department offices. The lines to the exchange are called *trunks*, while those to the telephones are called *auxiliary lines*, or *extension lines*.

The size of the switchboard required depends upon the necessary number of lines of these two classes. For example, if there are ten extension lines and two trunks required, the switchboard must have a capacity of 12 lines. Since telephone business grows, as a general thing, it is well to look to the future and provide a switchboard with a capacity somewhat in excess of the actual requirements. This practice allows of this class of switchboard being made in standard sizes, which are usually of 5, 10, 20, 40, 50 and 100-line capacities.

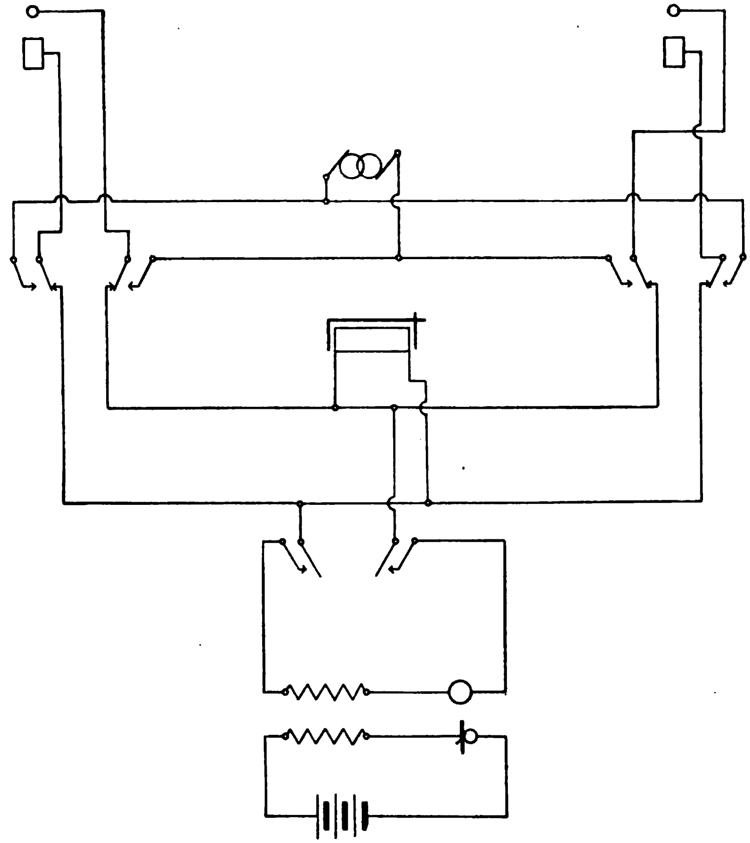


Fig. 300.

In design and construction these switchboards are of two classes. Those in which the connections are made by means of the usual connecting cords, called *cord boards*, and those in which the connections are established by means of keys, called *cordless boards*. The 5 and 10-line brand are usually of the latter class, while those of larger capacities are of the former type, on account of the excessive number of keys required were they constructed in this manner. The cord boards are of the type of the standard switchboard, but made of various sizes to meet the requirements of subscribers and with a view toward economy of space.

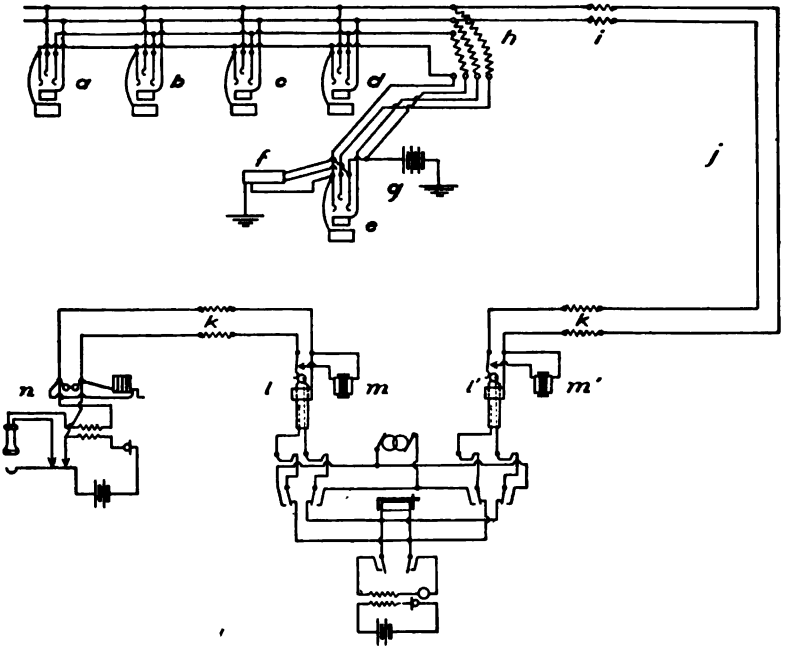


Fig. 301.

In Fig. 299 is shown the circuit of a trunk line terminating in a private branch exchange board; and in Fig. 300 is shown the wiring of the cord circuit and operator telephone set.

Referring to Fig. 299, the trunk is shown entering the office at *a*. It is wired in the same manner as an ordinary subscribers' line in every particular, and in the exchange is connected in the usual way to the proper subscriber multiple and answering jacks. At *b* is shown a small cross-connecting board, which is mounted in the rear of the private branch exchange switchboard. This cross-connecting board is constructed in a similar manner to that shown in Fig. 172. It is equipped with two rows of lugs, as 1 and 2, and 3 and 4. To the bottom row the wires from the outside are soldered while the line jacks, such as 5, are permanently wired to the other row, the circuits being completed by the cross-connecting wire shown by the broken lines. It will be seen that the circuit is the same as that of a subscriber line entering a standard switchboard.

Referring to Fig. 300, it will be seen that the cord circuit also is the same as that used on a standard switchboard. The ringing current generator is of the same type as that used on a subscriber telephone and is turned by hand. The transmitter battery is usually made up of two Fuller cells. The switchboard is designed for a capacity of 10 pairs of cord circuits; but where the full capacity is not needed, is only partially equipped. In private branch exchanges where the business is so heavy that it would be inconvenient for the operator to ring with a hand generator, ringing current is sent from the exchange over special conductors, and wired to the ringing keys of the private branch exchange switchboard. The extension lines are wired at the private branch switchboard end, as shown in Fig. 299.

In Fig. 301 is shown a complete connection between the exchange, and an extension station at a private branch exchange. Here the multiple jacks in the exchange are shown at *a*, *b*, *c*, and *d*; while the answering jack is shown at *e*, the drop at *f*, and the busy-test and restoring battery at *g*. The intermediate distributing board is seen at *h* and the main distributing board at *i*. The type of switchboard here shown is bridging, but might just as well be series. At *j* is shown the trunk to the private branch exchange, and it will be seen to be terminated at the connecting board *k*. The jack is shown at *l'* and the drop at *m'*. The extension telephone is shown at *n*, and it will be seen that the extension line is wired to the connecting board *k* as already described. The jack is shown at *l* and the drop at *m*. The connection is shown completed through the cord circuit. The connection at the exchange is put through in one of the many ways already described.

A connection between two extension stations is shown in Fig. 302, where it will be seen that the conditions are identical to that of a connection between two subscriber lines made over a standard switchboard.

In the case of a connection as shown in Fig. 301, the clearing out is simultaneous at the exchange and at the private branch. Both subscribers ringing off, throw the clearing out drops at the main exchange and also at the private branch. The operator at the private branch disconnects the extension line, while the operator at the main exchange supervises and asks: "Are you through?" The private branch operator who is listening in says "Yes," and clears the trunk. The connection is then cleared in the main exchange.

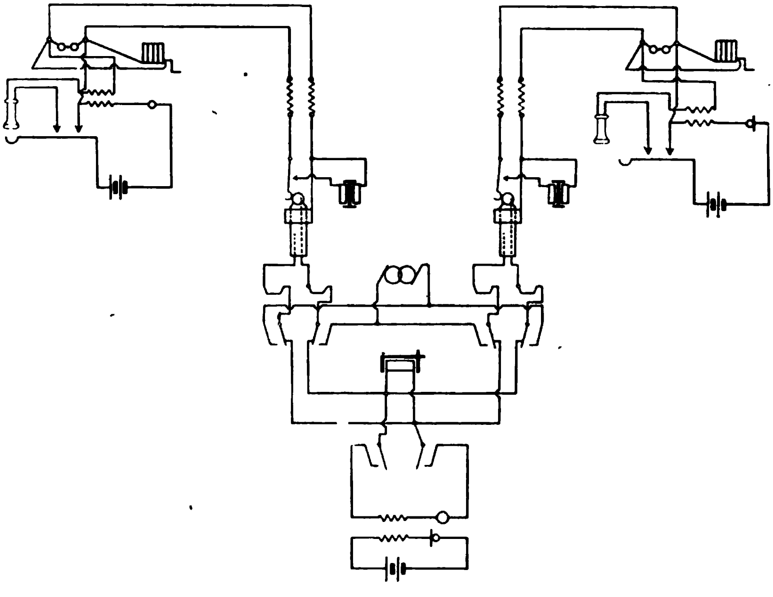


Fig. 302.

One of the most approved types of cordless private branch exchange boards is shown in Fig. 303. Here the lines are shown at 1, 2, 3, 4, and 5; they are wired to the middle contacts of the keys h, h^{I}, h^{II}, h^{III}, and h^{IV} respectively. These keys are constructed on the same principle as the ringing key, but are equipped with cams which normally keep the middle springs away from both the inner and outer contacts. When they are thrown one way, contact is made between the inner points and middle springs; and when thrown the opposite way, contact is made between the middle and outer springs. The outer springs of these keys are bridged together as are the inner contacts, so that

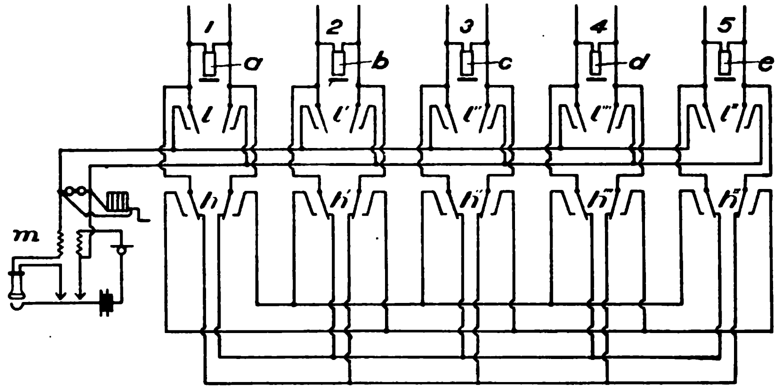


Fig. 303.

by wiring the cams of any two keys in the same direction the two lines wired to them are connected together, either through the inner or outer contacts. Bridged to each line is the line drop shown at *a*, *b*, *c*, *d*, and *e*. They are of the same construction as

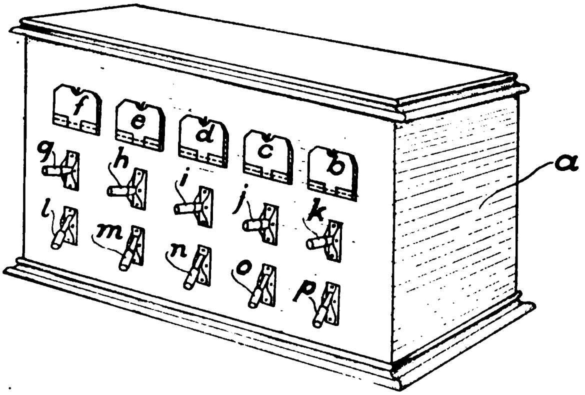
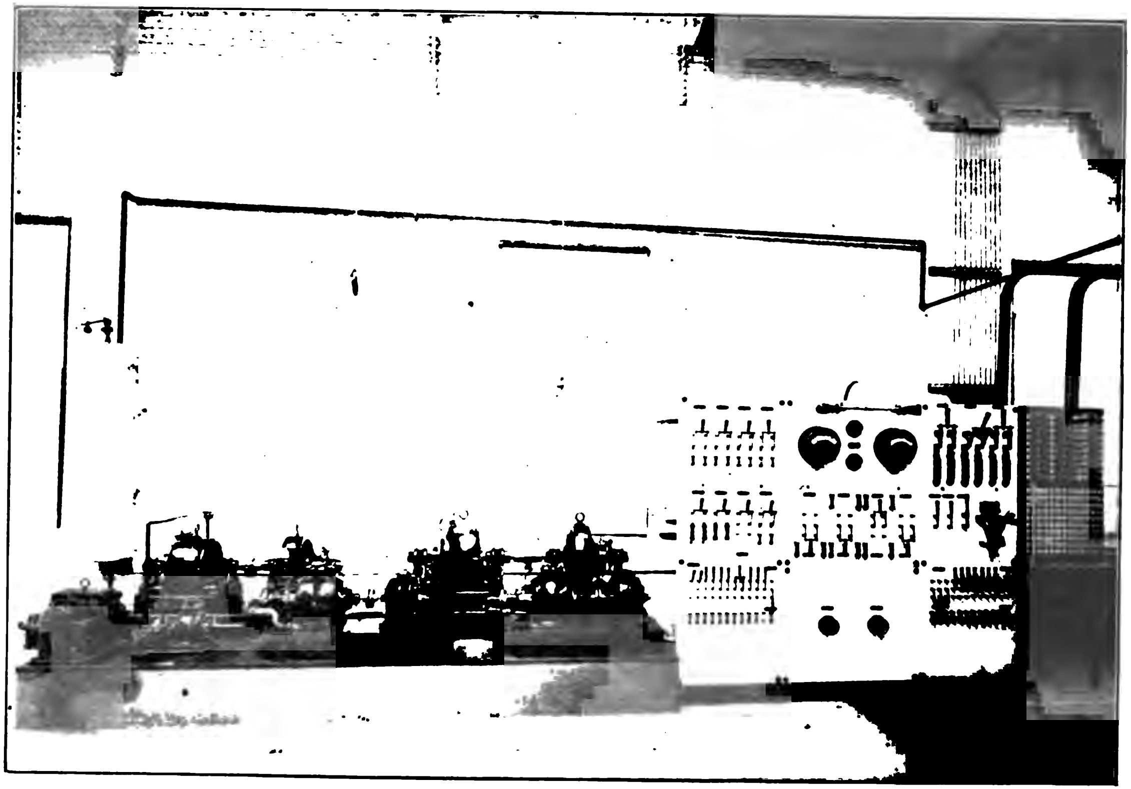


Fig. 304.

those used as clearing out drops, having a resistance of 500 ohms, and being surrounded with iron shells to prevent cross-talk. Also bridged to each line is a listening key l, l^{I}, l^{II}, l^{III}, and l^{IV}, all connected to the operator telephone set *m*.

The method of operating this board is as follows: Suppose that the subscriber on line No. 1 wishes to be connected to line No. 2. The line is rung on and the drop *a* thrown. The operator throws the listening key *l* and communicates with the calling party. To make the connection, keys *h* and h^{III} are adjusted to make contact on the outer contacts, and the circuit is established between the two. If while this connection is being maintained, and additional connection is required between line No. 2 and line No. 5, the keys h^{I} and h^{IV} are adjusted to make contact at the inner points, thus cutting the circuit through. Considering the number of keys required, this type of board is not flexible, as only two connections can be established at the one time. The advantages, however, lie in the small amount of space occupied by the board, and the ease with which it can be operated.

In Fig. 304 is shown a general view of this type of board The drops and keys are mounted in the face of a neat cabinet *a*. The drops are shown at *b*, *c*, *d*, *e*, and *f*, the connecting keys at *g*, *h*, *i*, *j*, and *k*, and the listening. keys at *l*, *m*, *n*, *o*, and *p*. The cabinet is designed to be mounted on a desk, and the wires are brought up through a hole in the bottom. The lid is hinged so as to lift up and give access to the inside.

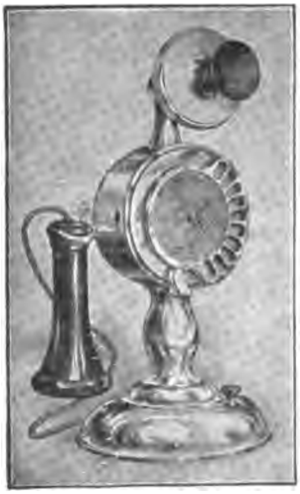


INTERIOR OF THE AUTOMATIC TELEPHONE EXCHANGE, LINCOLN, NEBRASKA.

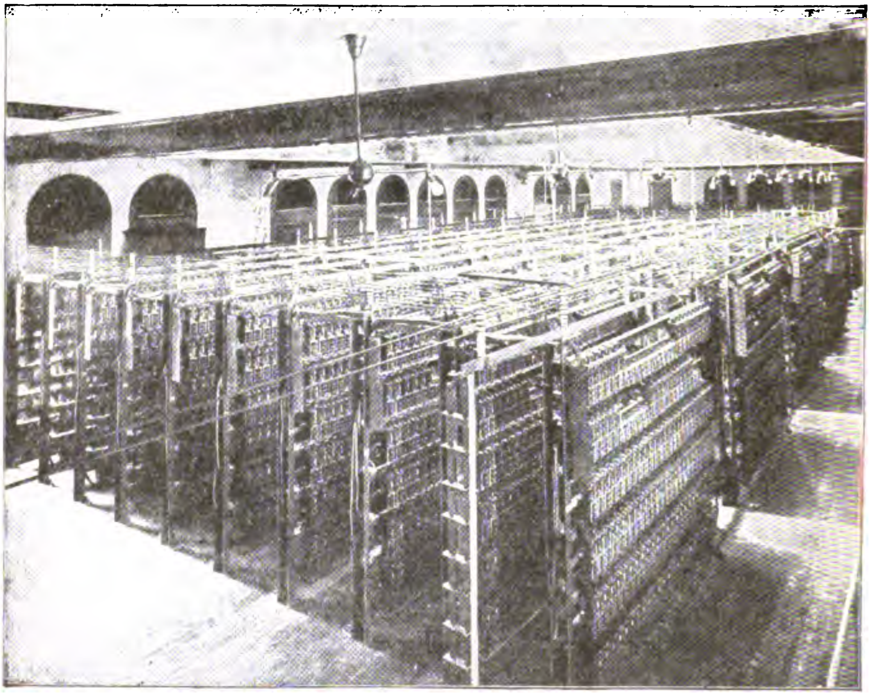
Showing the Power Plant of the Exchange.

AUTOMATIC TELEPHONY.

The spirit of the present age is not better shown forth than by the ever-increasing demand which industry, pressed by the keenness of competition, is making upon genius for the invention of labor-saving and time-saving machinery; and nothing pays higher tribute to the breadth of the human intellect than the character of the machinery which has been evolved as the result of this insistent call. Indeed, we are sliding rapidly into an automatic age. The work that once was done by hand, then by hand-guided machines, is now done by automatic devices. Scarcely a large, up-to-date factory but has in one or more of its departments a battery of automatic machines busily engaged in turning out such things as screws, buttons, tin cans, cloth, shoes, or a thousand other varieties of useful articles from the raw material, with surprising nicety and tremendous speed, reducing the cost of manufacture to a minimum and widening the field of sale. We have wondered at the ingenuity of these machines and marveled at their cleverness, but we have looked upon their invention and introduction as something that was bound to come, as only another step in the logical order of things. We have waited for them, and have not, therefore, been surprised at their successful advent.


Desk Telephone.

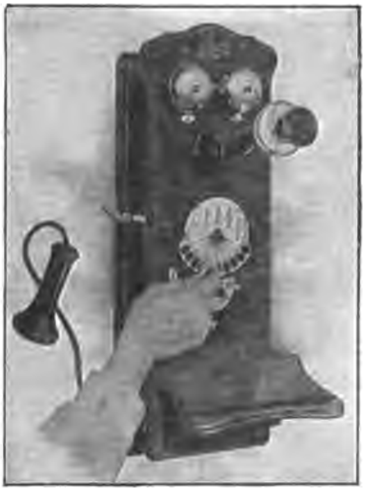
Few of us, however, as we have stood before a telephone box, wiggling a switch hook, or whirling the crank of a hand generator, and impatiently waiting for time and the "Hello girl" to bring us our connections, have ever gone so far as to hope, or even conceive the idea, that this genius who had so long presided over the central office, would ever be unseated and her place occupied by an iron machine whose speed and accuracy would discount her best performances, and yet that day is here. The States are already dotted with automatic telephone exchanges, which are giving service to thousands and thousands of subscribers, and with such success that it is not hazarding anything to predict that a few years will see the absolute divorce of the operator from the exchange room—except, of course, for long-distance calls, for which her services will probably always be needed.



Automatic Telephone Exchange, Dayton, Ohio.

Historical Retrospect. The application of the automatic idea to telephony is not new. It is considerably more than a decade since Strowger, an obscure Chicago engineer, brought out the first automatic telephone. The Strowger Automatic Telephone Company and the installation of a number of small exchanges resulted. These exchanges were successful, not so much in what they actually accomplished in the way of improved service, as in the promise they gave of future development in that direction. The apparatus was crude, imperfect, and complex; but the fundamental ideas involved were right and required only better expression.

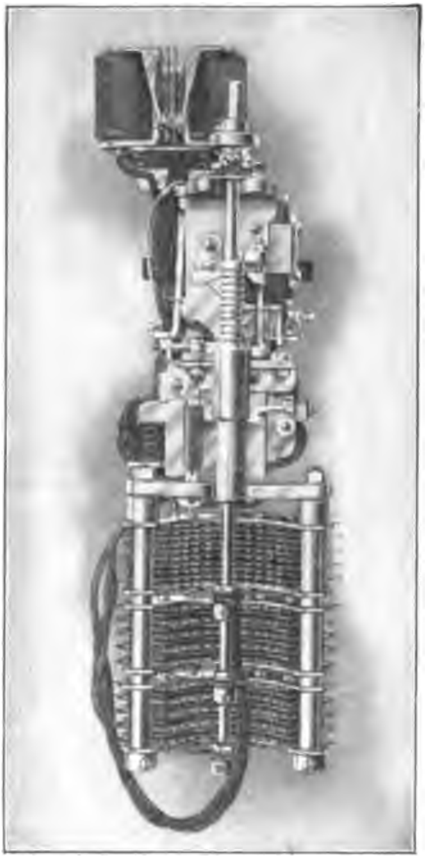
Ten years passed, ten years of experiment and persistent effort. Strowger died. The Automatic Electric Company was organized to take over the Strowger patents. Further experimenting was done, and greater capital expended. The result has been a system from which the imperfections have been eliminated, a system which is scarcely more complex than the manual switchboards now in general use. The limit of capacity is no longer reached at 1,000 stations. In fact, the business of the very largest city can be handled as efficiently and conveniently as that of a town which requires but a hundred telephones. In Chicago to-day an automatic exchange of 10,000 stations is already in operation, and others will be added as occasion demands, the ultimate purpose being to handle the business of the entire city.



Wall Telephone.
Showing Method of Operating Dial and Making Call.

The Automatic Mechanism. A study of the apparatus which has made all this possible, will, no doubt, be interesting and instructive. The telephone itself resembles, in many particulars, the manually operated telephones with which we are so familiar. It consists of the usual transmitter, receiver, bells, battery, and induction coil, adding only a calling dial, a circular metal piece, on the periphery of which are ten finger holes numbered 1-2-3-4-5-6-7-8-9-0. A stop is provided at the lower of the holes to limit the distance which the dial may be made to revolve.

How a Call is Made. The method of calling is very simple. To secure a number, say 761, the subscriber first takes the receiver from the hook; then placing his finger in hole number 7, pulls the dial around to the stop above mentioned. When released, the dial is instantaneously restored to its normal position. The subscriber is now connected to a trunk line leading to the seventh group of so-called "connector" switches, which we may call the "seven hundredth" group. In the same manner he calls 6 and 1 in this group. Having turned the number desired, he presses a button underneath the dial, which rings the bell of the person wanted, and the connection is completed. In the event that the 'phone of the subscriber called is busy at the time of the call, a vibratory sound in the receiver of the caller notifies him that such is the case.



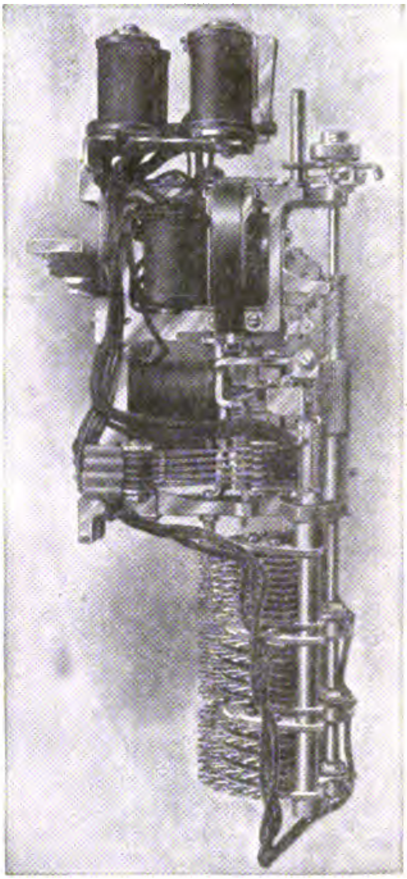
Automatic Telephone Switch.
Front View.

The keyboard or internal mechanism of the telephone, occupies a space 5×3×2 inches, and consists of an impulse-sending mechanism, which, in response to the rotations of the dial, communicates to the subscriber's switch a number of impulses corresponding to the number of the hole in which the finger is placed, lifting the shaft which occupies the central position of the switch, up to the proper row of contacts, and bringing the "wiping fingers" fastened thereto, into connection with the proper contact in that row.

It should be understood that, when the call is made, no impulses are sent over the line on the down movement of the dial, but on the return. This is arranged for the protection of the instrument against careless or hasty subscribers. The return of the dial is regulated by a governor which always insures proper speed.

The calling mechanism may be said to be perfect. It is simple, and works with remarkable accuracy, speed, and precision.

The Switch. The switch, shown in the accompanying illustrations, is a device about 13 inches in height, 4½ inches in depth, and 4 inches in breadth. The upper half of this device consists of two relays and three pairs of magnets mounted on a solid cast metal base. These relays and magnets, together with the proper springs, wires, etc., operate a vertical rod in the center, in obedience to the impulses sent from the subscriber's telephone, and bring the three pairs of "wiping fingers" attached thereto, into connection with the brass contacts, which, arranged in three semicircular banks, constitute the lower half of the switch.



Automatic Telephone Switch.
Side View.

The upper of these banks, known as the "busy bank", serves to indicate busy lines in the automatic selection of trunks. The lower two are "line banks", to which the line wires connect, and over which the conversation is held.

Two classes of switches are employed, one known as "selectors", of which there is one for every telephone connected with the exchange, and the other as "connectors", of which there are ten for every hundred selectors and which are in groups each capable of connecting one hundred telephones. The function of the selector is to connect the calling telephone with the connector in the proper group, which in turn connects with the telephone desired in that group. This is the case in exchanges of one thousand capacity or less. In larger exchanges a second collector is employed. This is an intermediate switch, and divides the work of selection with the first selector.

Trunk-Selecting System. The trunking system employed is very much akin to that now generally used in manual practice and, therefore, needs no description here. It may be said, however, that the selection of trunks is automatically accomplished, the "wiping fingers" on the shaft of the selector switch passing over all busy contacts and stopping at the first idle point.

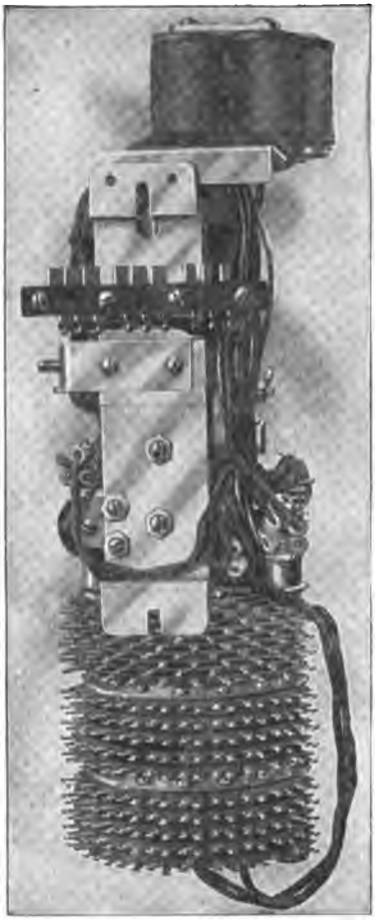
Accessories. The accessorial equipment consists of a 52-volt storage battery, which furnishes the current for operating the switches; a cross-connecting board or distributing rack, equipped with carbon lightning arresters and heat protectors; a ringing machine with "busy back" and "howler" attachment; charging machines; power board, on which are mounted the usual knife switches, circuit-breakers, voltmeters, ammeters, etc., necessary for controlling and measuring the current; and a "tell-tale" board.

Interior of Wall Telephone.

This last consists of a number of 8-candle-power lamps mounted on a marble panel, together with a magneto bell. In case of a short circuit or "ground" on any line, the bell rings and the lamp on the panel glows. The position of this lamp instantly indicates to the attendant the exact location of the trouble, and oft-times enables him to rectify it before the subscriber is aware that there has been any trouble.

The automatic switches are mounted on steel shelves, twenty-five to the shelf, each board containing four shelves of first selectors, and one shelf of connector switches. This is the arrangement for a system of 1,000 stations. In a 10,000-station system, the board is made up of six shelves, four of first selectors, one of second selectors, and one of connector switches. The floor space occupied by such a switchboard is 11 feet 6 inches by 12 inches. The switchboard is made of steel angles and is rigidly braced.

A very important feature of the automatic switchboard is that it can be increased to any capacity by simply adding new sections with the desired number of switches mounted thereon, without in any way interfering with existing conditions. Ninety-five per cent of the electric contacts and connections are made at the factory; consequently better results are secured, as well as time and expense saved in installation.



Automatic Telephone Switch.
Rear View.

Advantages of the Automatic System. 1. A switchboard has no operators; and thus one of the large fixed charges incident to manual-exchange operation is eliminated.

2. There being no operators, the automatic exchange can be located in less expensive quarters than the manual. No reading or retiring rooms are needed, no lockers, no lavatories; and the cost of fuel and lighting is reduced.

3. One switchboard attendant, for testing and keeping apparatus in order for 1,000 subscribers, is all that is needed in the automatic practice.

4. The cost of maintenance and interior equipment is no greater, and in large exchanges is less than in the manual exchange.

5. The service which the automatic system gives, unlike that of the manual system, is absolutely secret, each subscriber having a "private wire" on which to transmit his communication—an advantage that cannot be overestimated by the general business man, as well as by the broker, the lawyer, and the physician.

6. The subscriber himself instantaneously connects with the person he wishes to call; and the apparatus is so constructed that it is an impossibility for another subscriber to "cut in" or in any way interfere with the line he is using.

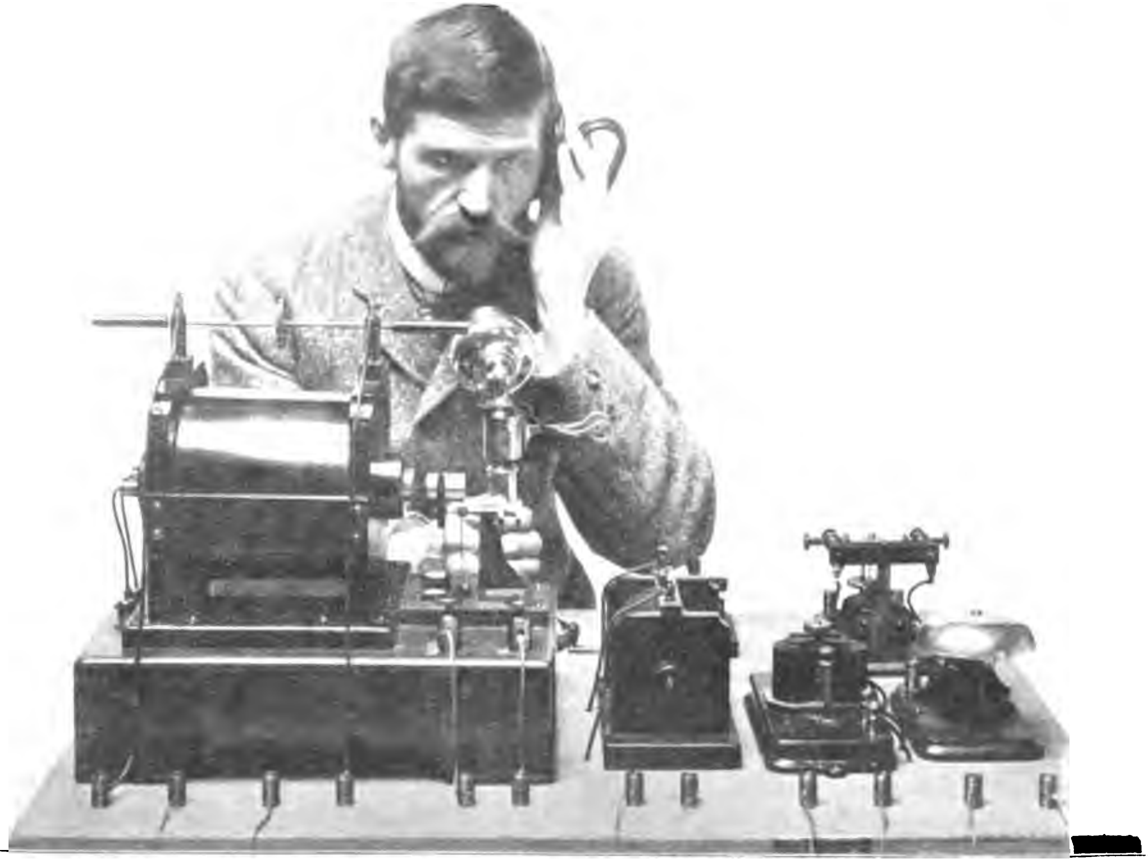
7. The frequent delays and mistakes which the manual board causes are entirely unknown to users of automatic telephones. The switches do not make errors nor gossip; are never weary or sleepy; are not interested in subscribers' affairs; and are not impudent.

8. The complexity of the automatic exchange does not increase proportionately to the increase of size, as is the case with manual exchanges, where the cost of giving service is much more per subscriber in large than in small exchanges. The cost of operation in the automatic exchange is fixed. An increase is merely a matter of adding new telephones and switches, the cost of operation being the same per subscriber.

9. The automatic switch is thoroughly cosmopolitan in its nature, no interpreter being needed by the foreigner in a country where the automatic exchange is located, any person being able to secure the desired connection by simple rotations of the dial.

10. The same number of automatic switches are always at work, night and day.

11. Quick connections, instantaneous accommodations, prompt answers, accuracy, and promptness, with the busy signal given when the subscriber called is busy.



SENDING AND RECEIVING A MESSAGE. COLLINS' SYSTEM.

WIRELESS TELEPHONY.

The transmission of intelligence by electricity has reached, in its broadest sense, its final stage of development.

Intercommunication by means of an electrical disturbance set up for the purpose of propagating energy representing the alphabetic code or articulate speech, may be divided into four general classes, namely, *telegraphy with wires*, *telephony with wires*, *telegraphy without wires*, and *telephony without wires*.

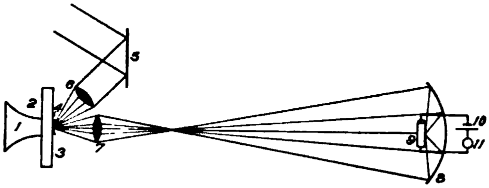


Fig. 1.

These principal classes may, it is evident, again be subdivided into many branches, but there can be no further evolution in the arts of sending and receiving messages by electrical methods, where instruments are interposed between those who are to be brought into mental relationship with one another.

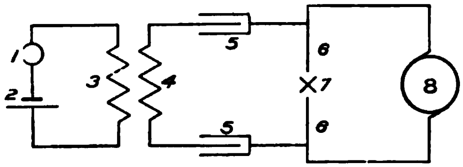


Fig. 2.

This is not to say that each of the forenamed systems approximate in their present state anything like perfection, for all are more or less crude in practice if not in theory, but any improvements that may be made in the future must be in degree and not in kind. Hence the *raison d'être* for the numerous arrangements for wire, and when wireless telegraphy made its spectacular début a few years ago, to the casual observer there seemed no good and valid reason why speech propagation and reception without wires were not already at hand, but to the investigator it was soon revealed that history was repeating itself and that wireless telegraphy and telephony were as different in all their phases as were their predecessors which utilized the connecting wire. A brief analysis of these differences that mark so clearly the dividing line between the four great classes enumerated, will assist materially in an understanding of the final principles of wireless telephony.

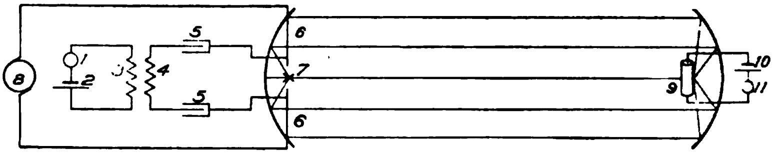


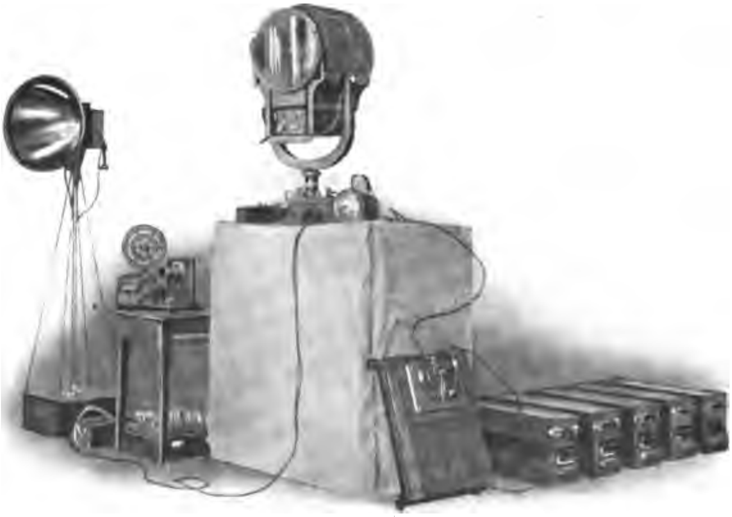
Fig. 3.

When Morse took up the study of telegraphy a working knowledge of the laws of electricity had not as yet been very accurately deduced. Induced and alternating currents had been explained by Henry and Faraday, but their usefulness remained to be indicated. It was well known, however, that a direct current traversing a wire was capable of energizing an electromagnet, and from this fact Morse conceived the idea of the relay—the device that made telegraphy a commercial factor.

Although nearly half a century elapsed before Bell made his successful essay to produce a speaking telephone, electricity had not made as much progress as might have been expected; Reis had attempted to construct a telephone by utilizing a rapidly intermittent current, and these futile trials led Bell to believe that such a method was impractical; experimenting with steel reeds vibrating over magnets he produced currents of varying strengths, termed undulatory currents, in virtue of their wave-like characteristics, and this formed the basic principle of the telephone.

In Marconi's wireless telegraphy any kind of a low-voltage current may be transformed into one of high potential and frequency, but the oscillations of such a transmitter emit their energy in the form of a train of waves with long intervals of time between them, and these are not, therefore, at all adapted to the transmission of voice undulations. There are several methods whereby articulate speech may be transformed into electric current waves which may, in turn, be propagated through the ether of the air, earth, or water.

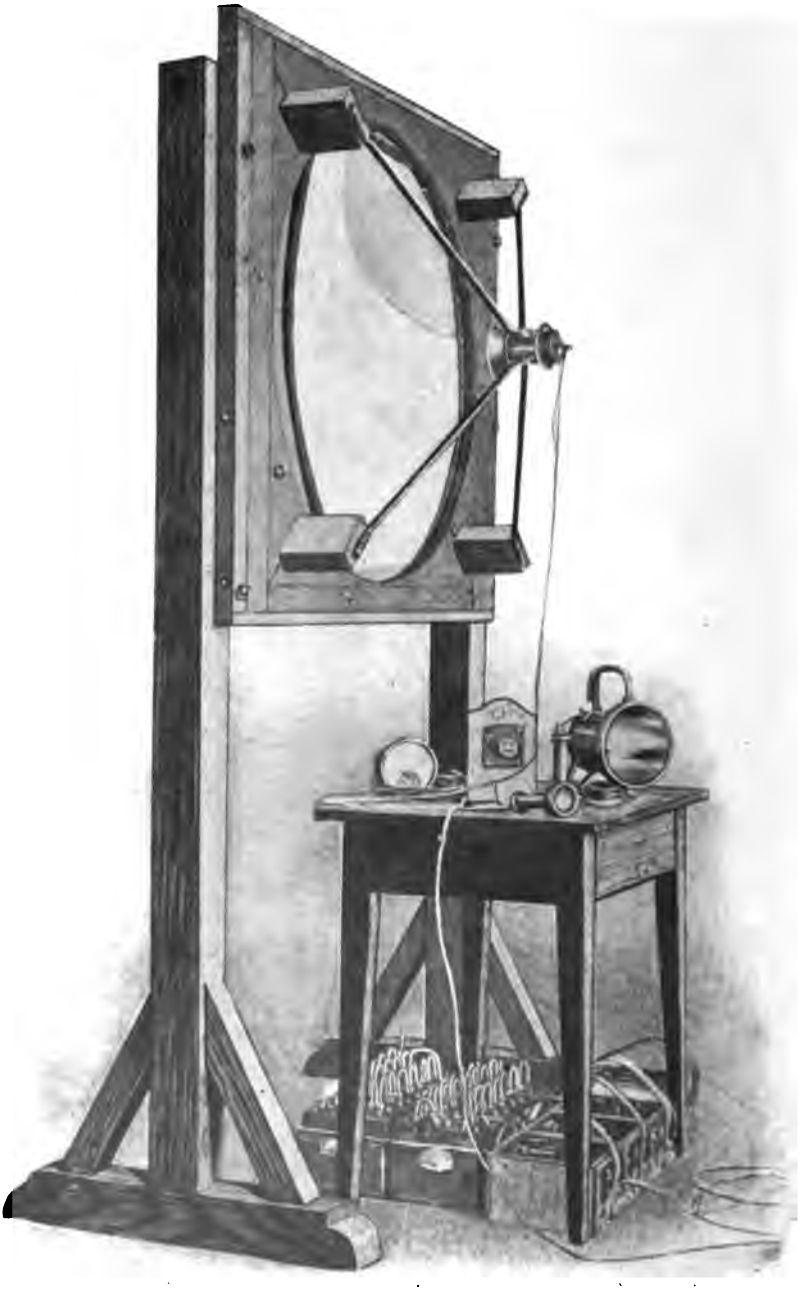
The *first* of these methods consists of a battery and a telephone transmitter connected in series, with the terminals which are embedded in the earth or immersed in the water, thus forming a circuit; when the undulatory current flows through it, the larger portion of the energy is dissipated, flowing out in curved stream lines, owing to the great cross-section of the earth, and extending to considerable distances. Now if a complementary equipment consisting of a telephone receiver is likewise in contact with the earth by having its terminals similarly grounded, when the energy impinges upon these the current then flows through the receiver and speech may be accurately reproduced.



Ruhmer Photo-Electric Telephone. The Transmitter.

Fig. 4.

A *second* method, ideal in its simplicity, is accomplished by electromagnetic induction; everyone knows that when a current flows through the primary of an induction coil alternating currents are set up in the secondary coil by what is called induction, but everyone does not know that these coils may be widely separated before the limits of the inductive influence will be reached. If, for



Ruhmer Photo-Electric Telephone. The Receiver.

Fig. 5.

instance, a telephone transmitter and a source of electromotive force approximating 25 volts are included in the circuit of a coil of wire having, say, 25 turns and a diameter of 5 feet, and a telephone receiver is included in a coil of wire having 60 turns and a diameter of 3 feet, words spoken into the transmitter may be distinctly heard in the receiver when the two instruments are separated a distance of 100 feet, providing, of course, that the coils have their planes parallel with each other. This is the inductivity method and like the one previously described, it is operated by a low-voltage direct current.

The invention of the telephone receiver led to many interesting experiments and to many curious discoveries. Bell in working with his new telephone devised an apparatus for telephoning on a beam of light. This instrument, which he named the *radiophone*, also involved the use of selenium, a substance that possesses the very remarkable property of varying in its electrical resistivity and its reciprocal when fused in between two connecting wires of platinum or silver.

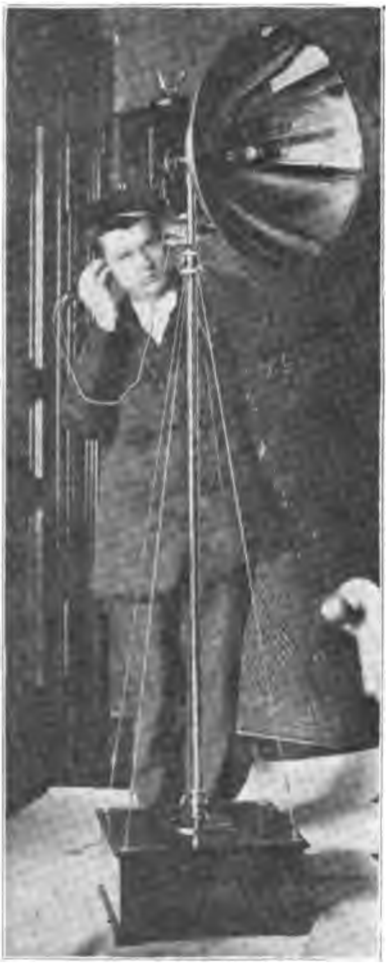


Fig. 6. Herr Ruhmer Receiving a Photo-Electric Message.

This apparatus is shown in the diagram, Fig. 1; the transmitter used by Bell was not electrical, for the transmitter as we know it had not been invented; it comprised the mouthpiece 1 and shell 2 for supporting a thin metal diaphragm 3; to the latter was attached a small concave mirror 4, a plane mirror 5, convex condensing lens 6, and projecting lens 7, all of which, suitably mounted on a frame, completed the apparatus for transforming the air vibrations produced by the voice into light variations of the projected beam.

The receiver was formed of a parabolic mirror 8 of large diameter and in the focus of this a selenium cell 9 was adjusted: the terminals of the conducting wires or electrodes of the cell led through insulated bushings in the reflector to the back where they were connected in series with a battery 10 and a telephone receiver 11. When in operation the successive transformations take place in the following manner—the light from the sun is reflected by the plane mirror 5 to the condensing lens 6 where its rays are focused on the concave mirror 4. From the latter the light is reflected to the lens 7 where it is propagated through the intervening space to the large parabolic reflector 8, where its diffused waves are collected and concentrated to a pencil point on the selenium cell 9. It is evident that any changes in the intensity of the light will change the resistance of the selenium cell, varying in consequence the current from the battery 10 and finally affect the telephone 11.

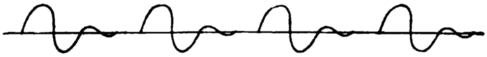


Fig. 7.

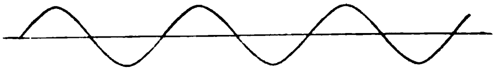


Fig. 8.

When words are spoken into the transmitter this is precisely what takes place, for the movements of the diaphragm of the transmitter cause the concave mirror to vibrate in unison with it and every change is thus indicated at the receiving end in virtue of these fluctuations. While the distance to which Bell was able to propagate the light variations representing the human voice was probably less than one hundred feet, recent improvements in the system by Herr Ernest Ruhmer have resulted in the transmission of speech a distance of several miles.

This was made possible through the remarkable advance of electro-physics during the past few years. Prof. H. T. Simon ascertained that an ordinary arc light could be made to reproduce articulate speech more clearly and distinctly than any phonograph by superimposing a feeble alternating current upon a heavy direct current. The diagram, Fig. 2, illustrates one form of the method by which this may be accomplished.

An ordinary telephone transmitter 1 and battery 2 are connected in series with the primary of a small induction coil 3; the secondary coil 4 leads through the condensers 5, 5 to the opposite carbons 6, 6, forming the electrodes for the arc light 7; the latter is produced by a direct 50-volt current from a generator 8 or, what is yet better, a storage battery. When the speaking arc or arcophone is operated, the voice causes the air waves to vary the resistance of the transmitter 1 in the usual manner; the current from the battery 2, thus varied, energizes the primary coil 3, setting up alternating currents in the secondary coil 4; the condensers 5, 5 produce no appreciable effect on the wave form of the current which is superimposed upon the current from the generator flowing through the circuit formed of the carbons 6, 6; arc light 7, and generator 8.

Ferryboat Ridgewood Equipped With Collins' Wireless Telephone.

Fig. 9.

The object of the condensers, however, is to prevent the direct current from backing up into the transmitter and burning it out. The superimposed currents, however feeble, vary the resistance of the arc, and this produces a change in its temperature which gives rise in turn to sound waves. Another important function of the speaking arc is that there is also a variation of the intensity of the light which it emits.

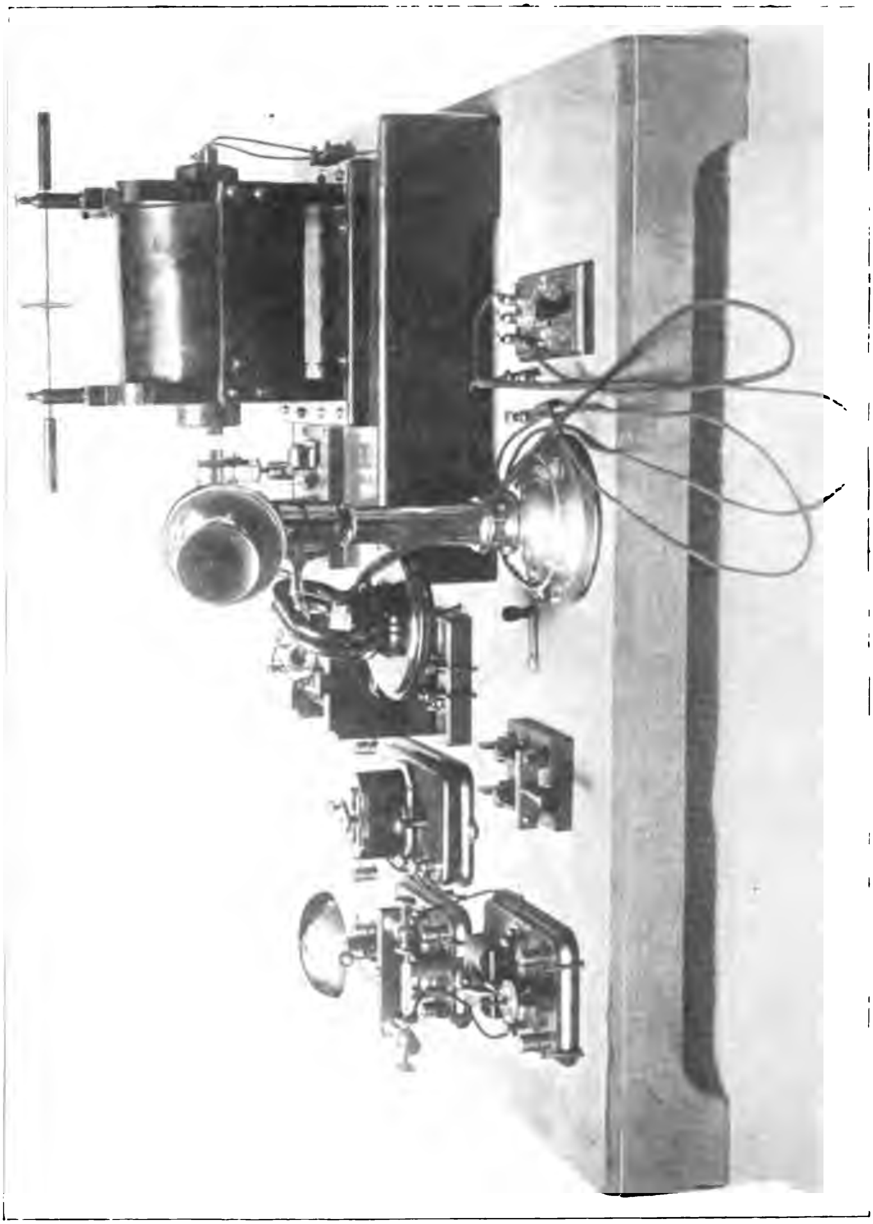
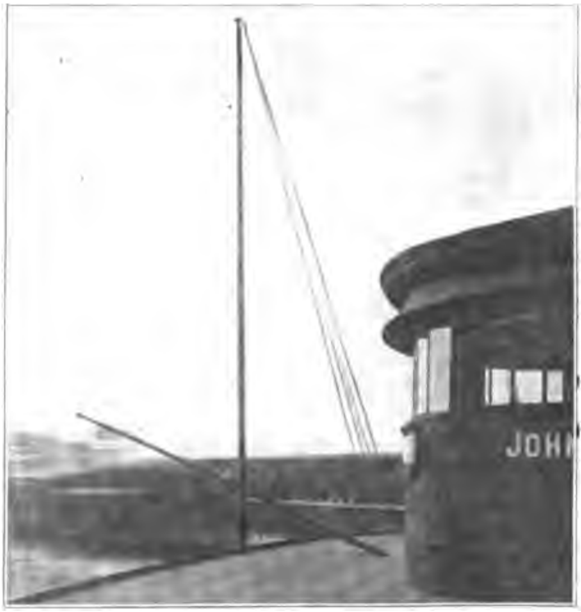


Fig. 10. Collins Wireless Telephone.

It is this by-product, as it were, of the speaking arc that Ruhmer employed in his photo-electric telephone which, in all other respects, is based upon the original Bell photophone. In Ruhmer's system the speaking arc is placed in the focus of a *parabolic reflector* whence its rays are directed to the distant receiver, and when the two are in perfect alignment the voice into the one will be distinctly audible in the other. The arrangement then takes the form shown schematically in Fig. 3, and with the description of the speaking arc and the selenium cell that have gone before, its action will be readily apparent. Figs. 4, 5, and 6 are photographs of the Ruhmer apparatus.



Upper Deck of John G. McCullough, Showing Aerial Wires Used in Collins' System.

Fig. 11.

The writer, A. Frederick Collins, in endeavoring to bring about the advent of a commercial wireless telephone that would not be interfered with by fogs or other conditions and would not require either alignment or a direct visual line, investigated the several schemes of dispersion, inductivity, and electromagnetic wave methods. The latter is the most interesting since it partakes of the nature of the wireless telegraph as well as of the wire telephone, yet it will do that which is not possible with either of the latter, *i.e.*, it will transmit articulate speech wirelessly.

In the beginning of this article it was pointed out that electric waves, when emitted by a high frequency and potential oscillation equalized through a spark gap, were periodic as indicated in the diagram, Fig. 7, the current strength decreasing in geometric progression like the vibrations of a straight steel spring. In wireless telephony an undulatory oscillation is required, and this may be obtained by loading the radiating circuit with large inductances and capacities whose coefficients possess the properties of slowing down each oscillation until a more or less perfect sine wave results as indicated in Fig. 8.

When this point is reached the striking effect of the oscillatory discharge on the ether is greatly weakened, but at short distances the telephone will respond audibly without the usual coherer intervening; some of the most recent work by the writer though, has shown that a liquid detector, made by immersing a platinum point and a platinum plate in an alkaline solution, increases the volume of sound to an appreciable extent.

The first series of tests with this type of apparatus was made at Rockland Lake, N. Y., a distance of a mile, while articulate speech has been transmitted and received under very favorable conditions a distance of three miles and a half. Tests were also carried out between the ferry boats John G. McCullough and Ridgewood, plying between New York and Jersey City.

Its final adoption will prevent collisions of vessels in harbors, while telephone communication between docks and vessels will facilitate transportation, saving time and money as well as insuring the safety of the passengers and crews. It is another step in the march of human progress.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART I.

1. What is the best feature in an induction coil, clearness or intensity?

2. Describe the nature of the alternating current.

3. Describe by means of a diagram the action of a Bell telephone.

4. Draw the circuit of a bridging telephone.

5 *a*. Why cannot the transmitter be used directly on the line? Explain fully.

b. How did Edison overcome the difficulty?

6. For commercial purposes what law does the fluctuation of current follow?

7. What are the actions that take place when sound is transmitted by the electric telephone?

8. What is a simple vibration? Complete vibration? Amplitude?

9. Draw the circuit of a telephone line equipped with four bridging instruments, and describe fully the method of operation.

10. What should be the shape and resistance of the coils of a receiver?

11. In an induction coil 10 c.m in length containing 50 turns of wire in the primary winding, how many lines of force would be produced by passing a current of .2 ampere if $\mu.=60$.

12*a*. What limits the distance over which sound can be transmitted by the Bell telephone?

b. What instrument was devised to increase this limit, and upon what principle did it work?

13. What is the resistance of a series bell?

14. Describe the "chloride" storage battery.

15. Sketch and describe some form of transmitter.

16. For telephone purposes what is the best construction for an induction coil and why?

17. Which would give the best results, a transmitter whose resistance varied from 10 to 5 ohms, working on a transmitter circuit of a resistance of 10 ohms; or the same working on a circuit of 100 ohms, the current in both cases being furnished by two Fuller batteries? Give comparative figures.

18. What is meant by magnetic lag and how does it affect an induction coil?

19. Give wiring diagrams of telephone.

20. What is meant by Pitch? Intensity? Character?

21. Draw the circuit of a series telephone.

22. Describe the automatic shunt, and automatic circuit closer, and give the reasons for their use.

23. What is gained by having the permanent field stronger than that produced by the induced currents in the coil?

24. Discuss the relative merits of the Gravity, Fuller, Leclanche and dry batteries, for use with transmitters.

25. What is meant by packing?

26. What is the resistance of a bridging bell?

27. Sketch and describe the Edison transmitter.

28. How does the local action announce itself at the receiving end?

29. What limits the size of the diaphragm of a receiver?

30. In the City of New York, assuming that 15 per cent of the calls sent by the telephones are for long distance points, what form of cell should be used on the transmitter batteries? Why?

31. When and where should Gravity batteries be used?

32. On a line 500 feet long, equipped with a telephone at each end, what type of cell should be used on the transmitters?

33. What should be the thickness of the diaphragm of a receiver?

34. When should Leclanche batteries be useo on transmitter circuits?

35. Describe the styles of hook switch used in connection with the American Bell Telephone Co's. bridging and series bell.

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART II.

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1. Draw the diagram of a pole showing the typical equipment.

2. How are telephones classified?

3. How should poles be guyed in passing through hilly country?

4. What is meant by distribution?

5. Of what material are insulators made?

6. Draw a standard pin, for standard and terminal cross-arm. Also draw a transposition pin, for standard and terminal cross-arm.

7. What is a terminal cross-arm? Give drawing.

8. Draw a standard pole.

9. Describe fully the method of stringing wires.

10. What is a McIntire sleeve?

11. Give a table of allowable sag.

12. Describe in detail the method of setting a pole.

13. Is a pole ever placed in the center of a stream? If so, when?

14. What is a cable line, when should it be used, and what are the advantages it possesses?

15. Describe fully the method of placing cross-arms, giving diagrams.

16. Discuss fully the relative merits of iron, copper, and aluminum for use in the manufacture of telephone wire.

17. What is meant by an open-wire line?

18. What is the reason for creosoting wood?

19. Discuss fully the subject of pole fittings, giving diagrams.

20. What precaution must be taken crossing a river?

21. What is a Western-Union splice?

22. How are calls between two towns best handled?

23. What points must be observed in the construction of a telephone line?

24. Describe fully the method of fastening cross-arms.

25. What is meant by back-guying, side-guying, and head-guying?

26. In going through hilly country, how should the line be graded?

27. What is the difference between subscriber lines, trunk lines, and toll lines?

28. Why is it not possible to connect all telephones in a district to one line? Explain fully.

29. What is the minimum allowable height of the lowest wire above the ground?

30. What kind of wood has superseded cedar, and why is it used?

31. What kind of a splice is used in line construction? Describe fully.

32. How should guying be done when the pole is equipped with two or more arms?

33. Discuss fully the method of calculating the area of a wire section in circular mils.

34. When are back braces used, and how are they placed?

35. Describe fully the method employed in crossing roads.

36. Describe fully the manufacture of a standard cross-arm. Give drawing.

37. What advantage is gained by placing the guy stub near the foot of the pole? Explain this point fully.

38. What is meant by an exchange, and how is it used?

39. Draw a standard insulator and a transposition insulator. Describe fully.

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART III.

1. Explain the process of transposing the lines of a telephone circuit.

2. What is a drip loop, and what is its purpose?

3. What precautions should be taken in climbing a pole?

4. Describe the action of a come-along.

5. What is a chipping knife? Describe its use with sketch if necessary.

6. How does the 4a type of main distributing frame differ from the 4b type?

7. About how far apart should the manholes be in a subway?

8. Why does transposing reduce cross-talk?

9. Into what two classes may rubber-insulated cables be divided?

10. Describe the most approved method of stringing cable.

11. Describe the so-called pump-log type of duct.

12. What is a spinning jenny, and why is it going out of use?

13. Without referring to the text make a sketch of a scheme for transposition.

14. What do you consider a good method of fastening a rope to the end of a cable which is to be drawn in?

15. What are test points, and how frequently should they be placed on a line?

16. How would you tell when paraffine is at the proper temperature?

17. What is a jack?

18. Describe a method of numbering the conductors entering an exchange.

19. Why cannot a subway be continuous from start to finish?

20. What is a manhole? Describe with sketch.

21. What do you understand by a cable box? Describe its construction.

22. Describe with sketch the method of drawing in cables.

23. What is meant by cross-talk?

24. What means have been devised for supporting the messenger wire of an aërial cable?

25. Describe with sketch the effect of electrostatic induction on a telephone wire of a neighboring wire carrying an alternating current.

26. Which do you consider to be the cause of cross-talk, electrostatic or electromagnetic induction?

27. In making a wiped joint what precautions should be taken?

28. Describe fully the effect of magnetic induction of a wire carrying an alternating current upon a neighboring telephone wire.

29. How did the Chinnock and Law systems differ?

30. What are the advantages and disadvantages of underground cable lines?

31. What is meant by a pot head?

32. What is the usual construction of a submarine cable?

33. Describe with sketch the wiring of a test pole.

34. In laying underground cables, why was it necessary to draw them into some form of duct?

35. Describe the mandrel used in laying ducts for underground cable work.

36. How does a clearing-out drop differ from a line drop?

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART IV.

---

1 What is meant by a full multiple switchboard?

2. Why were primary batteries superseded by storage batteries?

3. How are calls handled in a standard board?

4. What is the standard potential for the common battery system?

5. What are stripping trunks and how are they used?

6. In the manufacture of switchboard cables, how are the wires distinguished?

7. What is the use of a self-restoring drop?

8. Of what two classes are multiple switchboards?

9. Draw and describe the operator's cord circuit.

10. What is meant by a disconnect signal?

11. How is a cable formed?

12. What is a multiple switchboard?

13. What kind of a drop is used on a bridging board and how is it wired?

14. What are circuit trunks?

15. What points should be observed in soldering wires?

16. Draw and describe the most advanced type of trunk between bridging boards.

17. What is the use of the condenser in the subscriber telephone?

18. What are the two types of switchboards?

19. What are ring-down trunks?

20. What is meant by the common battery system?

21. What is a standard switchboard?

22. What piece of apparatus was brought out in connection with the bridging board?

23. What two types of power apparatus are used in a telephone exchange?

24. What is gained by the use of the common battery system?

25. What is a subdivided multiple board and what advantages does it possess?

26. How does the operator make use of the busy test?

27. What are the requisites of a charging dynamotor?

28. What is gained by using circuit trunks?

29. How was transmission carried on with the Stone system?

30. Describe fully the method of trunking between standard boards.

31. What is meant by a busy test, and what is the necessity of it?

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART V.

---

1. What two types of circuit have been devised to overcome the click heard in the ear when the operator answers a call?

2. Why are outgoing local trunks and toll trunks multiplied every five panels in the toll board? Explain the point fully.

3. What three classes of boards are used in a long-distance office?

4. What is meant by shunting out a lamp?

5. What are the duties of the recording operator?

6. Describe fully the method of handling a call between two subscribers whose lines are in the same exchange both with the magneto and with the common battery system.

7. What are the duties of a supervisor?

8. Describe fully the method of handling a call with the common battery system.

9. What two purposes are toll boards used for?

10. What is meant by operating?

11. How many kinds of service do telephone companies give and what are they?

12. What three classes of calls are handled in a long-distance exchange?

13. Describe the method followed in putting a call through the recording board.

14. Draw and describe fully a trunk from a magneto to a common battery office.

15. What is the nature of the business done by the Long-Distance Company?

16. How is the force in a telephone exchange made up?

17. In connection with what classes of calls are tickets used?

18. What is meant by a "lost call", and how can the percentage of lost calls be reduced?

19. What is the trunk line relay?

20. Why are not subscribers' lines multiplied every five panels in the subscriber board?

21. What are the duties of the monitor?

22. What is meant by the *tandem trunk* method?

23. On all trunks from local battery to common battery exchanges, what is the method used at the sending end, to properly work the signal at the incoming end?

24. What is the circuit trunk equipment of a toll board?

25. How would a call from Washington to Boston be put through New York?

26. What are the duties of the manager?

27. What point is gained in a trunk between two common battery exchanges?

28. Are busy visuals used on circuit trunks? Give the reasons fully.

29. What are the duties of the chief operator? Explain this point fully.

30. How are the hours of the operators arranged, and why?

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY.

PART VI.

---

1. What did Pupin's discovery consist of?

2. What general plan is followed by the wire chief in making tests?

3. How do the subscribers call the operator?

4. What two forces of men are occupied in the work of cable maintenance?

5. If the wire chief should receive a report that the operator could not ring a subscriber, but that conversation could be carried on over the line, what kind of trouble would he expect to find, and how would he make his test?

6. What analogy exists between the transmission of wave motion over a cord, and the transmission of electrical wave motion over a conductor?

7. In regard to a private branch exchange what is meant by a trunk?

8. What are the Murray and Varley loop tests and when are they used?

9. What is meant by the term "party line"?

10. How are load coils connected to a line?

11. How can you determine with the voltmeter, the presence of a ground?

12. Describe in detail the nature of the tests used by the galvanometer man in determining the capacity and insulation resistance of a cable.

13. What is meant by "load coils"?

14. What two types of private branch exchange switchboards are there?

15. What is the best type of galvanometer for the use of the galvanometer man ?

16. How are heat coils tested ?

17. Define capacity reaction, inductance reaction, and resistance reaction.

18. What points limit the number of instruments that can be successfully operated on one line ?

19. How does the galvanometer man proceed in locating trouble ?

20. What three reactions are set up in a circuit over which an alternating current is flowing ?

21. How is a ground in the multiple located ?

22. What does the work of the galvanometer man consist of ?

23. Suppose that a kite tail fell across the two conductors of an open-wire line, on a foggy day, what would be the nature of the trouble caused ? Give reasons for your decision.

24. How is a cross detected and how is it located ? Describe fully the method of testing.

25. What is a private branch exchange ?

26. Describe in detail the method of locating an open.

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OF THE

Cyclopedia of Applied Electricity.

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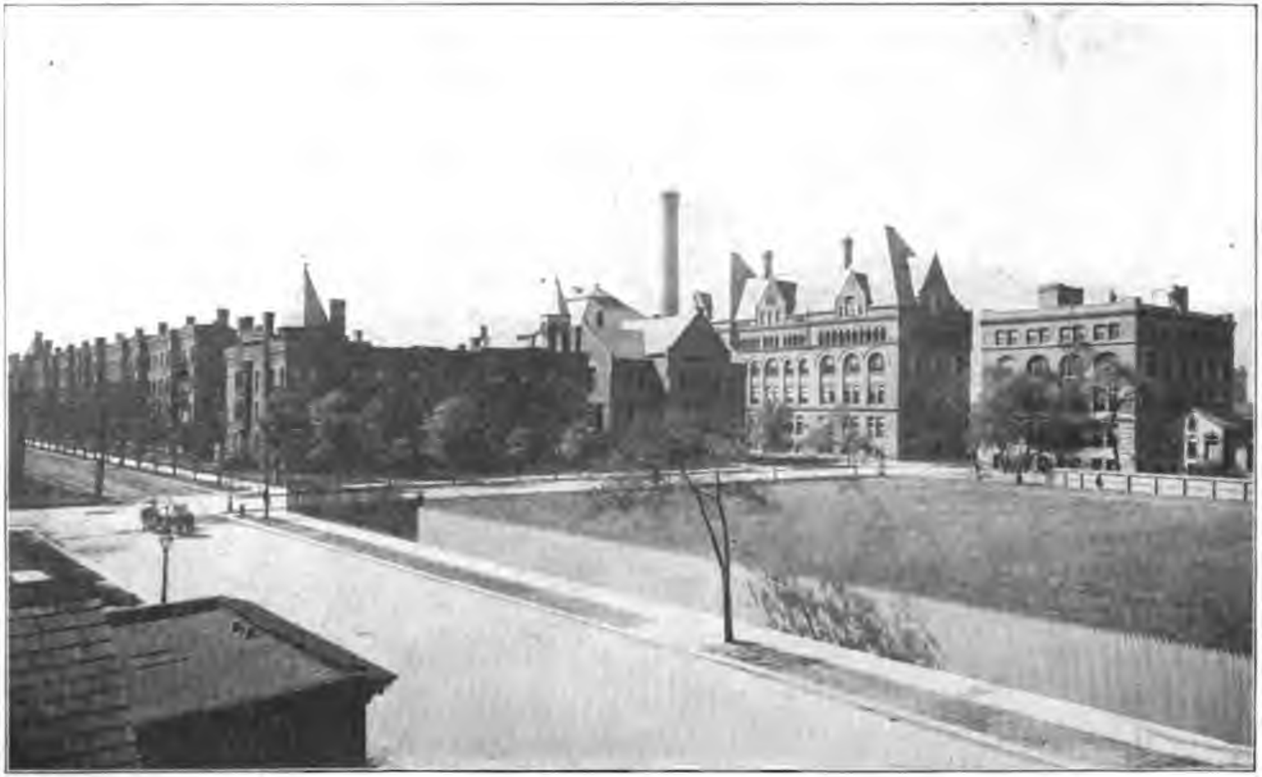

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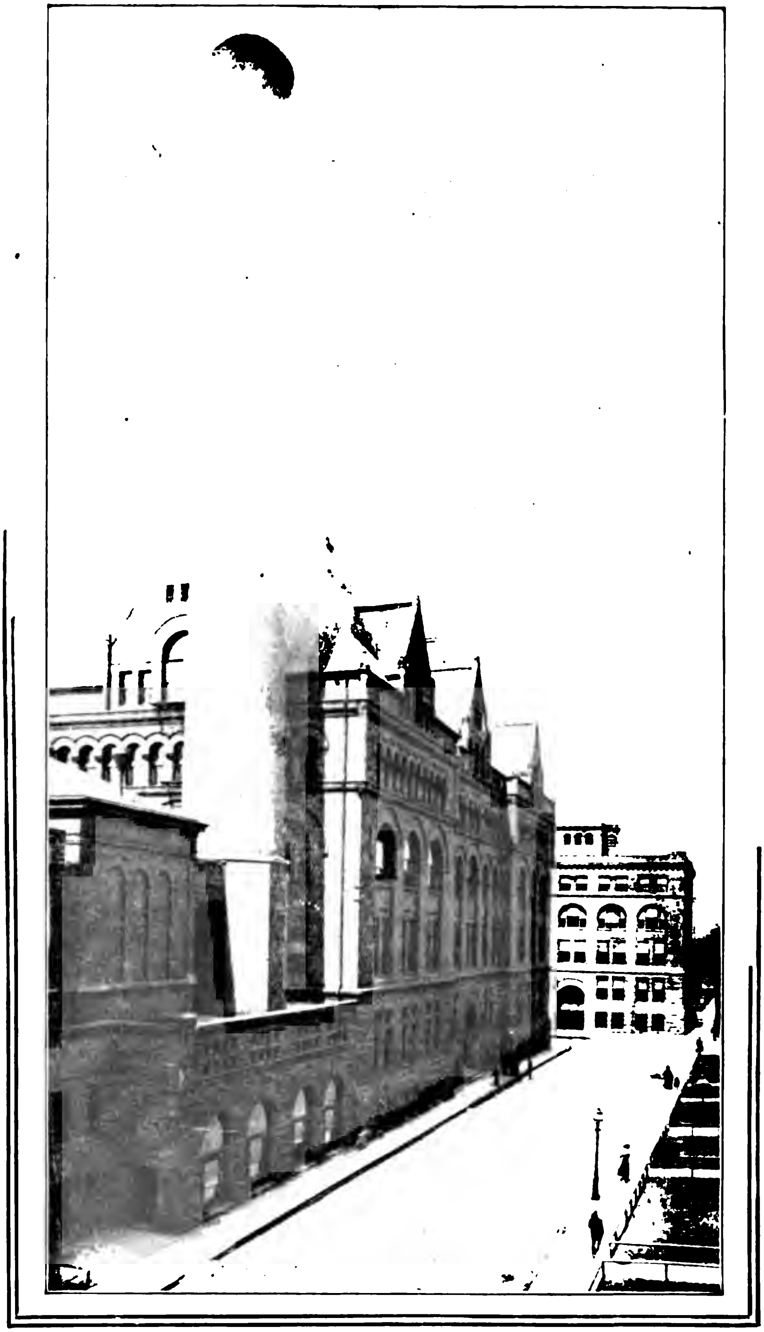

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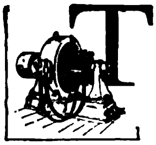

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Alternating Current Machy. Part V.
Alternating Current Machy. Part VI.
Mechanics. Part I.
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Types of Boilers.
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Mechanical Drawing. Part IV.
*Mechanical Drawing. Part V.
*Mechanical Drawing. Part VI.
Machine Design. Part I.
Machine Design. Part II.

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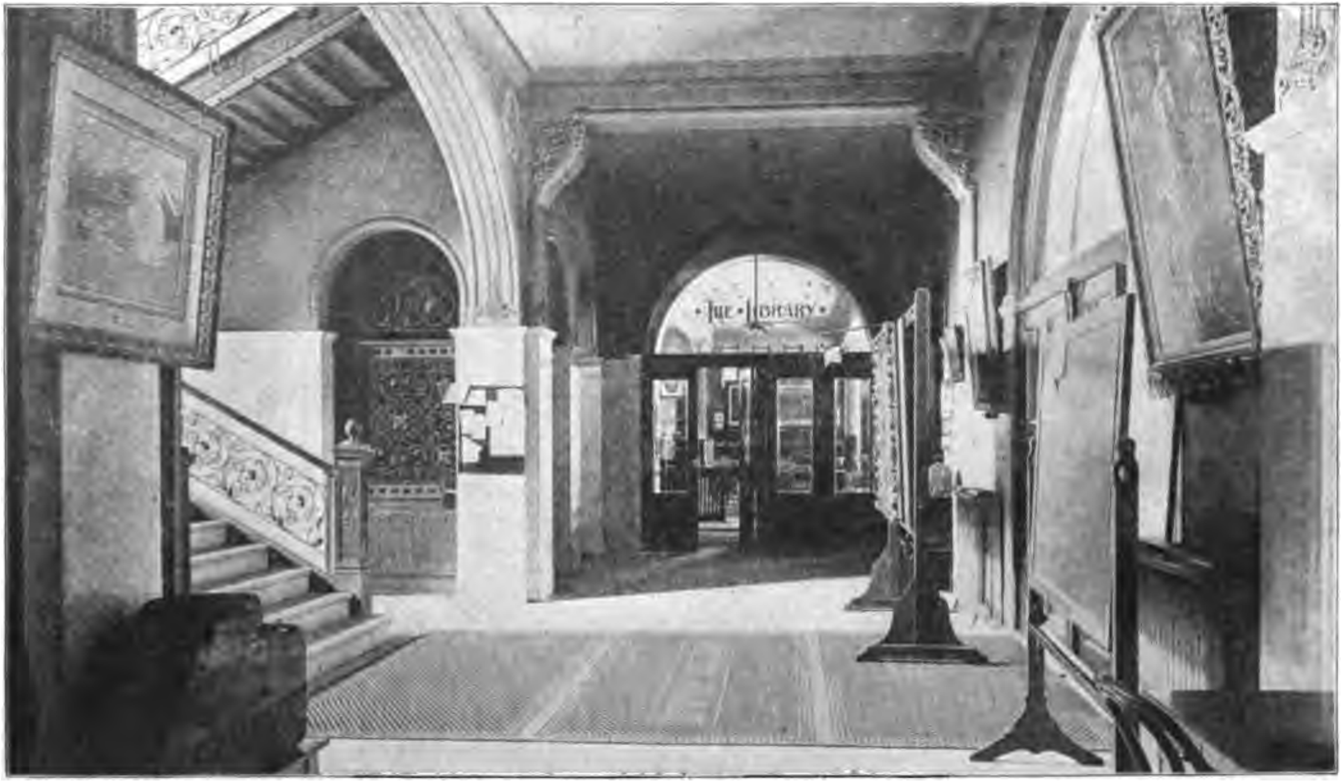
*Optional.

NOTE: The Instruction Papers prepared by Prof. Wm. Esty, *head of the Department of Electrical Engineering, Lehigh University, on* Alternating Current Machinery, *describe the latest machines and their operation and explain the advanced theories without the use of higher mathematics. The papers on* Management of Dynamo Electric Machinery, *by* Prof. F. B. Crocker *(joint author with S. S. Wheeler of "Practical Management of Dynamos and Motors") give the most recent and best practice on this subject, and in* Electric Railways, *prepared by* James R. Cravath, *Western Editor "Street Railway Journal," will be found the most recent developments, including elevated railway work, with full treatment of the Third Rail, Multiple Unit, and Alternating Current Systems; Magnetic Brakes, Air Brakes, and Safety Arrangements.*



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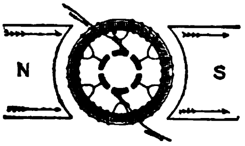
MENSURATION, MECHANICS, MECHANISM,
HEAT, ELEMENTS OF CHEMISTRY, METALLURGY

ELECTRICITY

ELEMENTS OF ELECTRICITY: Magnetism; Magnetic Induction; Static Electricity; Insulators; Conductors; Charges; Electric Machines; Condensers; Dynamic Electricity; E.M.F.; Resistance; Cells; Solenoid; Electro-magnets; Induction Coils; Applications; Telephone; Telegraph.



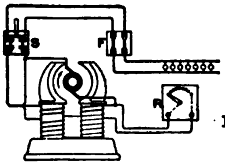
ELECTRIC CURRENT: Resistance; Conductance; Tables; Calculations; Coefficients; Wire Tables; Ohm's Law; Circuits; Fall of Potential; Electric Energy; Power; Coulomb; Joule; Watt; Mechanical Equivalent; Plants.

THEORY OF DYNAMO-ELECTRIC MACHINERY: Symbols; Lines of Force; Induction; The Generator; Commutator; Permeability; Saturation; Hysteresis; Armature Reaction; Neutral Point; Lead; Demagnetization; Types of Fields; Series, Shunt and Compound Windings.

DIRECT CURRENT DYNAMOS: Constant Current; Constant Potential; Characteristic Curves; External; Internal; Total. Long and Short Shunt. Magneto-motive Force; Magnetic Reluctance; Magnetizing Force. Field Magnets. Dynamo Construction: Armature; Armature Core and Windings; Binding Wires; Closed and Open Coil Armature Commutators; Brushes; Brush Holders; Field Magnets and Coils. Sparking. Installation. Operation. Testing.

DIRECT CURRENT MOTORS: Principles; Equations: Counter E. M. F.; Torque and Speed; The Prony Brake; Shunt and Series Motors; Compound Motor; Series Motor; Regulation; Transformers; Generator and Motor in Combination; Calculations.

TYPES OF DYNAMO-ELECTRIC MACHINERY. DIRECT CURRENT. Classes; Methods of Driving; Types: General Electric; Crocker-Wheeler; Westinghouse; Bullock; C and C; Holtzer-Cabot, etc.: Electrolytic Work; Arc Lighting Generators; Railway Motors; Motor-Generators and Dyna-motors.



MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY: Selection; Erection; Connection; Operation; Construction; Handling; Regulation; Foundations; Installation; Belts; Assembling; Wiring; Circuit Breakers; Circuits; Starting; Stopping; Generators in Parallel; Generators in Series; Three-wire System; Inspecting; Testing; Detection and Remedy of Troubles; Sparking; Heating; Noise; Railway Motors.

ELECTRIC WIRING: Wires; Coverings; Joints; Wiring Fixtures; Cleats; Casings; Tunnels; Switches; Plugs; Sockets; Fuses; Meters; Applications; Plans and Specifications; Fire Risks; Insurance Rules and Regulations; Inspectors.

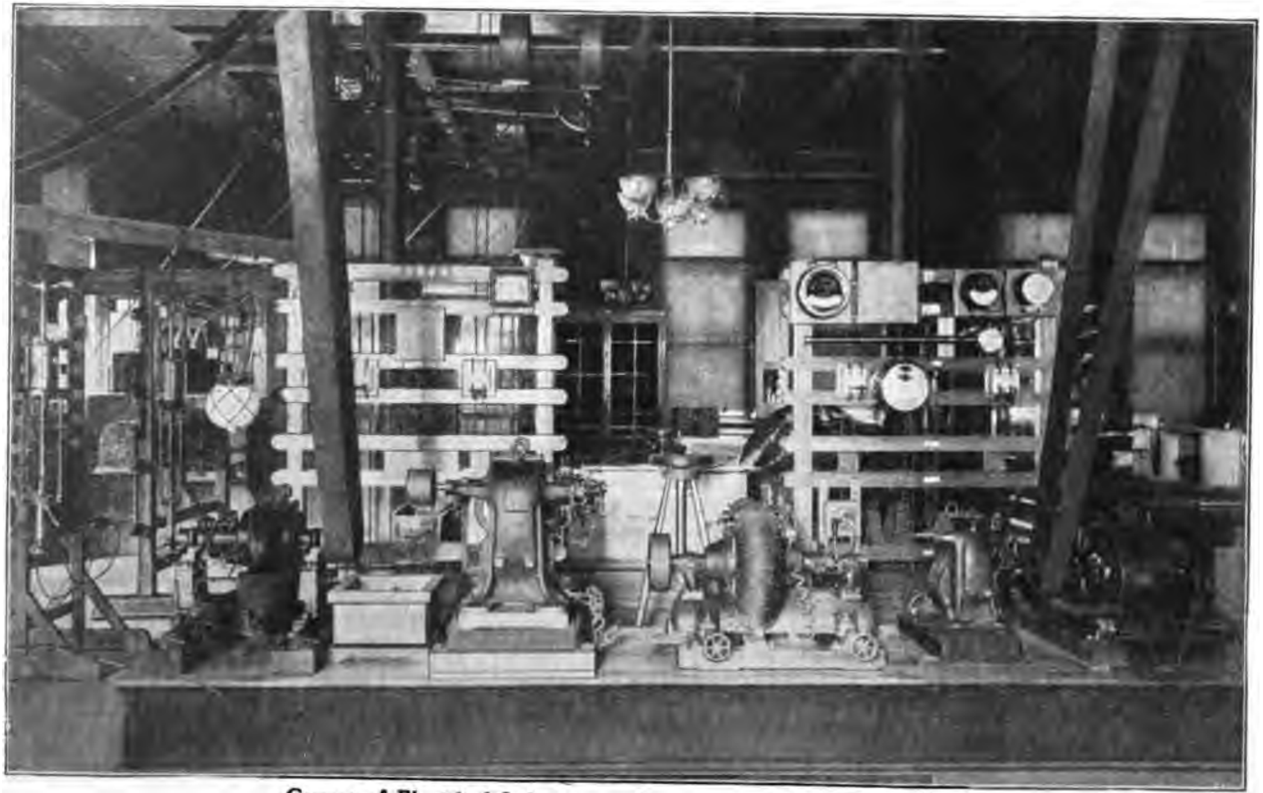
STORAGE BATTERIES: Plante; Faure; Forming Plates; Setting up; Electrolyte; Tests; Discharging; Efficiency; Sulphating; Buckling; Disintegrating; Short Circuiting; Over Discharging; Uses; Connections; Diagrams; Switches; Regulation of Charging Generator; Boosters.

ELECTRIC LIGHTING: Lamps; Candle Power; Incandescent Lamps; Arc Lights; Systems of Distribution, Feeders; Potential; Location of Lamps; Power Required; Location and Equipment of Plant; Overhead and Underground Systems; Wiring of Buildings; Size of Wire; Calculations.

ELECTRIC RAILWAYS: Car Equipment; Armature Coils, Loads and Brushes. Inspection; Gearing; Lubrication; Bearings; Motor Suspension; Controllers and Car Wiring; Series Parallel Control; Rheostat Control; Controller Construction and Wiring; Magnetic Blow-out; Multiple Unit System; Car Heaters; Car Wiring; Resistances; Car Accessories; Trucks; Brakes; Air Brake; Magnetic Brake; Car Bodies; Overhead Construction; Trolley Wire; Feeders; High-Tension Lines; Third Rail; Conduit System; Track Construction; Joints; Bonding and Return Circuits; Electrolysis; Power Supply and Distribution; Alternating Current Transmission; Power Station; Switch Boards; Alternating Current Systems; Operation; Testing; Faults.

ELECTRICAL MEASUREMENTS: Units, Symbols for Physical Quantities. Galvanometers; Rheostats; Voltmeters; Ammeters; Wattmeters; Measurement of Resistance. Locating Faults; E. M. F. of Alternating Currents, Calibration of Voltmeters and Ammeters. Measurement of Energy, Quantity and Capacity.

ALTERNATING-CURRENT MACHINERY: Simple Alternator; Alternating E. M. F. and Current; Armature Cores and Windings; Cycle; Graphical Representation; Average Values; Effective Values; Form Factor; Instantaneous and Average Power; Harmonic E. M. F. and Current; Definitions; Synchronism and Phase Difference; Maximum and Effective Values; Expression for Power; Inductance; Capacity; Reactance; Impedance; Fundamental Equation; Resonance; Measuring Instruments; Measurement of Power; Armature Reaction; Alternator Regulation; Excitation; Single Phase Alternator; Polyphase Alternator; Armature Winding; Types; Losses; Efficiencies; Ratings; Tests; Synchronous Motor; Transformer; Transformer Connections; Regulation; Types; Tests. Rotary Converter; Power Ratings; Induction Motor; Stator Winding; Motor Generator; Switch Boards and Station Appliances.



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POWER STATIONS: Location; Buildings; Machinery; Measuring Instruments; Switchboard; Starting; Stopping; Faults in Generators and Motors; Accumulators; Charging and Discharging; Troubles.

POWER TRANSMISSION: Line loss; Direct and Alternating Current Systems; Voltages; Wiring; Transmission Lines; Losses; Illustrative Installations.

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- Elements of Electricity.
- The Electric Current.
- *Theory of Dynamo-Electric Machinery.
- Types of Dynamo-Electric Machinery.
- Electrical Measurements.
- Telephony Part I.
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- Telephony Part VI.

*Optional.

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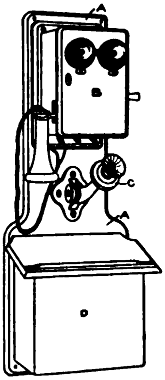

SOUND AND ELECTRICITY: Electrical Energy, Batteries, Primary and Secondary Alternating Currents, Magnetism, Induction, Dynamos, Electro-Static Capacity.

HISTORY: Bell Receiver, Microphone, Early Transmitters, Modern Forms, Hunnings-Hughes, Berliner, Blake, Solid Back.

TELEPHONE INSTRUMENTS: For Talking, Signalling, Bells, Generators, Complete Telephone—Bridging and Series.

TELEPHONE LINES: Arrangement, Metallic and Grounded Circuits, Distribution in Outline, Trunk Lines, Toll Lines, Subscriber Lines.

LINE CONSTRUCTION: Classification, Open Wire Lines, Materials of Construction, Poles, Pole Fittings, Cross Arms, Erection of Poles, Stringing Wire, Guying, Aerial Cable Lines, Stringing Suspension Wire, Suspension Cable, Cable Cross Arms, Underground Cable Lines, Subways, Manholes, Pulling in Cables, Splicing and Pot Heading, Terminal Points, Test Points, Distributing Points, Submarine Cable Lines.

PROPERTIES: Transmission, Noisy Lines, Heavy Lines, Cross Talk—by Line, by Central Office Apparatus. Remedies. Retardation Coils, Repeating Coils, Transposition, Pupin's Load Coils.

TELEPHONE EXCHANGE: Systems of Operating in Outline, Switchboards, Standard, Multiple, Special, Main Distributing Board, Intermediate Distributing Board, Exchange Wiring, Subscriber and Trunk Circuits, Order Circuits, Office Circuits, Power Apparatus, Primary Batteries, Secondary Batteries, Charging Machine, Ringing Current Machine, Special Machines.

TELEPHONE OPERATING: Operating Force, Operating Systems, Standard Board, Local Calls, Trunk Calls.

TOLL OPERATING: Toll Boards, Toll Lines, Long Distance Switchboards.

TELEPHONE SYSTEMS: Direct Line, Party Line, Code Signalling, Selective Ringing, B. W. C. System, Four Party Systems, Automatic Systems, House Systems, Private Branch Exchanges.

COMMON BATTERY SYSTEM: Theory, Switchboard, Subscriber's Apparatus, Circuits, Auxiliary Apparatus.

TELEPHONE MAINTENANCE: Testing and Clearing Trouble, Wire Chief's Desk, Testing Circuits and Apparatus, Wire Chief's Force, Method of Reporting and Clearing Trouble.

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Types of Dynamo-Electric Machinery.
Electrical Measurements.
The Electric Telegraph Part I.
The Electric Telegraph Part II.

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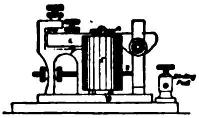

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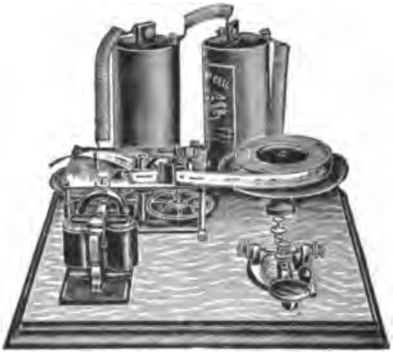

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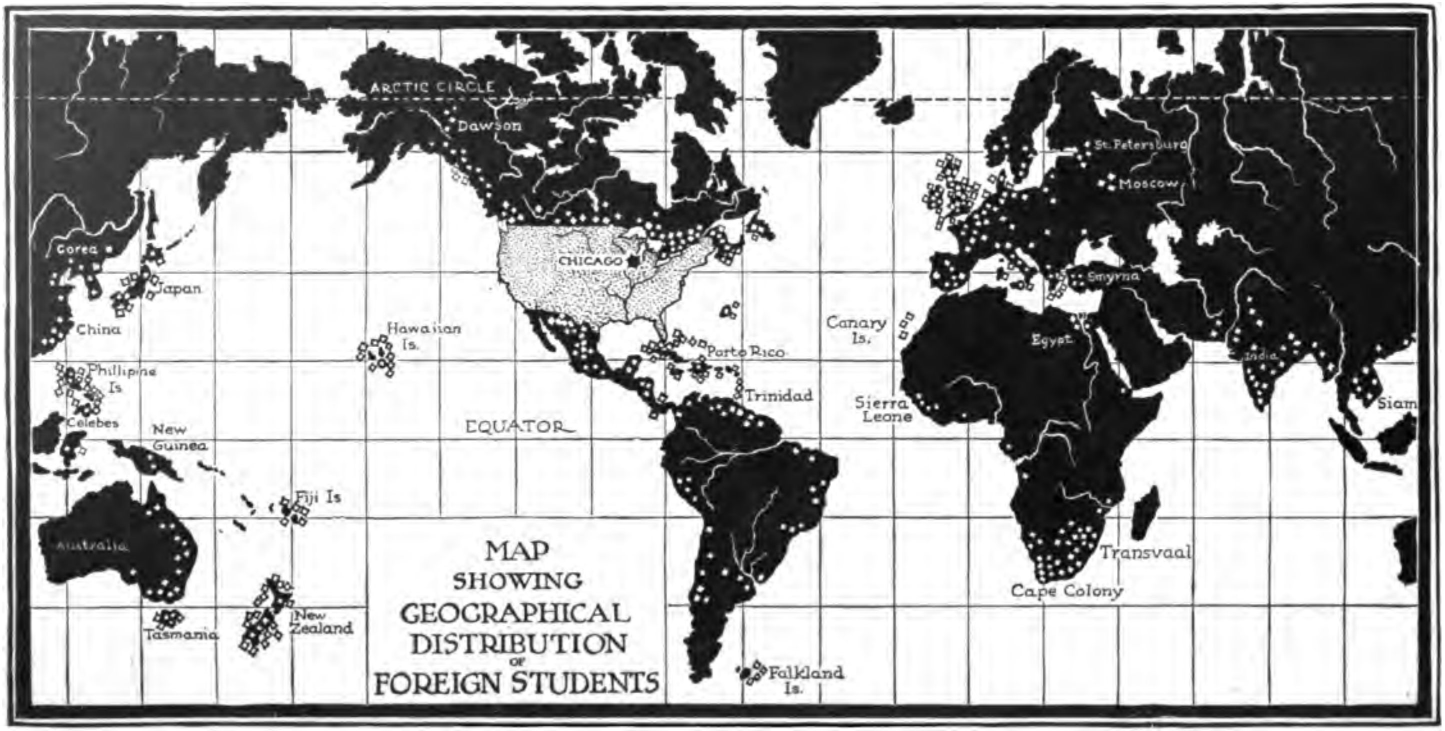
- Electric Lighting.



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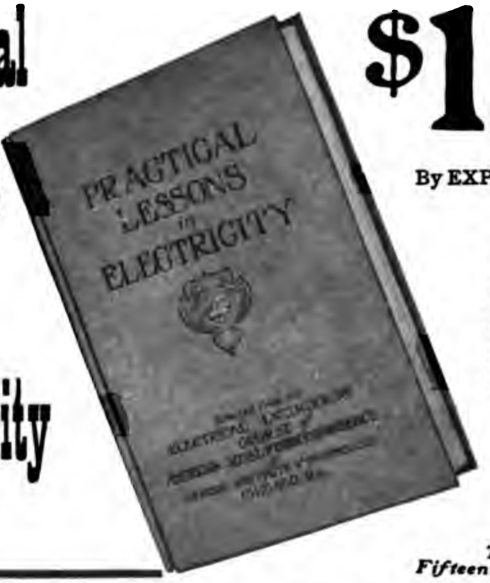

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